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EDITED BY
MADISON BENTLEY, UNIVERSITY OF ILLINOIS

HOWARD C. WARREN, PRINCETON UNIVERSITY (*Review*)
RAYMOND DODGE, YALE UNIVERSITY (*Monographs*)
S. W. FERNBERGER, UNIVERSITY OF PENNSYLVANIA (*Bulletin*)
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HERBERT S. LANGFELD, PRINCETON UNIVERSITY, Business Editor

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Journal of
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VOL. XI., No. 3 June, 1928

BEHAVIOR WITH RESPECT TO SHORT TEMPORAL STIMULUS-FORMS

BY HERBERT WOODROW

University of Oklahoma

PART I

SOME HITHERTO UNDESCRIBED ILLUSIONS IN THE ESTIMATION OF SHORT INTERVALS OF TIME

The illusions to be here described consist of errors made in reports upon the relative length of various short 'empty' intervals of time. They are dependent upon the duration of the sounds used to bound, or limit, these intervals. These illusions were encountered in the course of an investigation designed to lead to an explanation of the well-known effect upon rhythmical grouping exerted by the introduction into a series of sounds of regularly recurring variations in duration.[1] These illusions are deemed worthy of a special study. Aside from their intrinsic interest and in addition to their immediate bearing upon the nature of the perception of time and of rhythm, they have a bearing upon certain current problems, of a rather general nature, concerning the psychology of perception.

The intervals used occurred in what will be termed isolated temporal forms, *i.e.*, such a combination of stimuli as might constitute a single measure in a rhythmical series of sounds (*e.g.*, two short sounds bounding a single, short, 'empty' interval of time). The reason for referring to two such sounds separated by an interval of silence as a single

[1] For an account of duration of stimulus as a rhythmical factor, see the writer's A quantitative study of rhythm, *Arch. of Psychol.*, 1909, no. 14, 38–52.

temporal form is the well-known fact, confirmed by the experiments described below, that, providing the interval between the sounds is sufficiently short, the subject cannot react to the interval in complete independence of the sounds.

With respect to these temporal forms two kinds of behavior have been studied; that of comparison (reports on relative length) and that of reproduction by means of tapping. Part I of this study is concerned with the results obtained when the subjects' responses consisted of reports and Part II with the results secured by the method of reproduction. The reports of the subjects were made in response to instructions to compare two intervals of silence, the intervals compared being differently bounded as regards the lengths of their limiting sounds. Under these conditions, marked *constant errors* or illusions were found. The results include a total of 29,000 reports or judgments obtained from 95 subjects and are therefore sufficiently abundant to yield a high degree of certainty as regards the existence and the magnitude of the illusions upon which the investigation concentrated.

To facilitate the description of intervals and their limiting sounds, a special nomenclature will be used. The term *interval* will always be used to mean the period of silence between two sounds, that is, the time elapsing from the end of one sound to the beginning of the succeeding sound. The relative length of the sounds limiting or bounding any interval will be indicated by the letters *l* (longer), and *s* (shorter), and the interval between the sounds will be designated by a dash (–). Thus the form *l–s* means an interval beginning at the end of a relatively long sound, *l*, and terminating at the beginning of a relatively short sound, *s*. If *l* equals .45 sec, *s*, .06 sec and the interval, .50 sec, the form *l–s* would represent a combination of stimuli as follows:

.45 sec	.50 sec	.06 sec
(sound *l*)	(silence)	(sound *s*)

Apparatus and procedure. The sounds bounding the intervals were produced by means of an electric buzzer,[1a]

[1a] For a description of the buzzer used and its advantages, see H. A. Richmond, this JOURNAL, 1917, 2, 100–105.

of a frequency of 1700 dv. per sec. The tone was smooth and entirely free of both initial and final clicks.

The duration of all sounds and intervals was controlled through the use of a Meumann's time-sense apparatus. The longer sounds were produced by the rotating contacts and the shorter sounds by the contact of a platinum brush attached to one of the rotating bars. This brush made contact with a flat and narrow strip of copper mounted so as to fit onto the calibrated rim of the machine. The time-sense apparatus was connected by waxed rope-belts with a 110-volt, d. c. motor, with adjustable resistance speed-control. With this arrangement a high regularity of speed could be maintained; but throughout the work the calculation of the duration of all sounds and intervals was done from long-roll kymograph paper on which was recorded the vibration of a 100 dv. tuning fork, marking alongside an electromagnetic recorder connected in parallel with the buzzer.

In the experiments by the method of reproduction, every stimulus-form and every reproduction was measured individually by aid of the tuning-fork record. In the experiments described in this section—group experiments by the Method of Constant Stimuli—this was impracticable. The rate of rotation was carefully regulated by the graphic method, at the beginning of each hour's work, and watched throughout by means of a speedometer. While perfect accuracy was of course unobtainable, it may be safely said that all intervals to be mentioned below were accurate as regards their true average length to less than one per cent. As an indication of the constancy of speed obtained, measurements may be cited for a time interval, intended to be .50 sec, given every third revolution of the bars of the Meumann. Measurements of ten successive intervals, the bars of the machine being reset each day, on each of ten days, gave the averages and mean variations.

TABLE I

CONSTANCY OF INTERVALS

Intended interval (based on previous graphic measurements) = .50 sec

Day	Av. Obtained Interval	$M.V._{dis}$	$M.V._{av}$
1	.492 sec	.018	.006
2	.506 "	.007	.002
3	.493 "	.013	.004
4	.483 "	.031	.010
5	.502 "	.014	.005
6	.513 "	.012	.004
7	.494 "	.025	.008
8	.507 "	.018	.006
9	.501 "	.009	.003
10	.484 "	.023	.007
Av.	.4975 sec	.0170	.0055

Experiment on l–s compared with s–l. Especial study was made of judgments of the relative length of two intervals, one of which began at the end of a long sound and ended at

the beginning of a short sound and the other of which began at the end of a short sound and ended at the beginning of a long sound (*l–s* compared with *s–l*). As will be seen from the data presented below, there is a very striking relative overestimation of the interval in *l–s* (or underestimation of the interval in *s–l*). This illusion comes out definitely by each of the three methods by which it has been studied, the methods of constant stimuli, minimal changes and reproduction. The data obtained by the first method will be here described.

To a group of thirty subjects, constituting a laboratory class in psychology, a series of four hundred pairs of intervals was presented. The experiment was divided into two two-hour periods, with 5 minutes of rest between the first and second hours of each period. One-hundred trials were made during each hour. Each trial resulted in a judgment of the relative length of two intervals—the standard and the variable interval. The standard interval (always one of the pair of intervals on which judgment was passed, and constant throughout) was the interval of the form *l–s*. In this stimulus-form, the duration of the interval was .50 sec, of *l*, .50 sec, and of *s*, .08 sec. The duration of *l* was therefore slightly over 6 times that of *s*. The variable interval was the interval occurring in the form *s–l*, in which *s* and *l* had exactly the same length as in the *l–s* combination. Five different lengths of the variable interval were employed; namely, .40, .53, .66, .79 and .92 sec. Every judgment, then, was a judgment of the length of one of these five intervals, occurring in the form *s–l*, relative to that of the standard interval of .50 sec, occurring in the form *l–s*. In one-half the trials the interval given first was the standard, and in the other half it was the variable interval. These two time-orders, standard-variable and variable-standard, were mixed in random order, as were also the five lengths of the variable, though for each successive 100 trials the order of events was exactly the same. It follows that the subjects never knew whether the variable or the standard would be given first nor what would be the length of the variable. No facts

concerning the absolute or relative lengths of any intervals were known to the subjects.

The experiments were performed in a large laboratory, so spacious that the apparatus for controlling the sounds emitted by the buzzer could be placed too far from the nearest subject to be disturbing. Approximately 1.5 sec before the beginning of the first form the experimenter, who was invisible behind a screen, called 'Now.' After the first stimulus-form, no further signal was given. The subjects simply waited for the second form. The interval between the end of the first form and the beginning of the second was 2.2 sec. The warning signal before the first form was given orally, instead of mechanically, so as to cause it to stand out distinctly separate from the sounds composing the stimulating forms.

The subjects were not aware that the experiment was concerned with an illusion. They were told that the object of the experiment was to determine the accuracy with which they could judge the length of short intervals of time. To keep them from wondering about the unequal lengths of the two sounds bounding each interval, they were told that it had been found that judgments of the intervals under such conditions were more accurate because of the avoidance of monotony. When, at the conclusion of the experiment, these statements were retracted, it was ascertained that no subject had had even a suspicion that the experiment dealt with an illusion. The subjects were allowed to use the terms *longer*, *shorter* or *equal*, but were asked to make their judgments, so far as possible, in terms of *longer* or *shorter*, and to reserve the term *equal* for cases where the intervals really sounded equal rather than to use it simply as a synonym for doubtful. With these instructions the number of *equal* judgments obtained was comparatively small, constituting but 7.9 per cent. of the total number. In the statistical treatment of the data, the *equal* judgments were divided evenly between the judgments *longer* and *shorter*.

It is important to note that the subjects were instructed to judge the relative lengths of the intervals (the intervals of silence between the sounds) and that it was definitely explained to them what was meant by intervals of silence by means of blackboard diagrams. They recorded their judgments on prepared blanks, by means of the symbols *l*, *s* and =, always recording the judgment which applied to whichever interval was given second.

In the tables and graphs presenting the results, only the 'variable longer' judgments will be recorded. Since the 'equal' judgments have been divided equally between the 'longer' and 'shorter' judgments, obviously the number of 'variable shorter' judgments is equal to the total number of judgments minus the number of 'variable longer.' It should be mentioned, however, that, in the tables and graphs, those judgments are labelled 'longer' which *signify* that the variable is longer. From the fact that the subjects' judgments, as given, always applied to whichever interval came second, it follows that in that half of the trials in which the standard interval came second, a judgment recorded by the subject

as 'shorter' would signify 'variable longer.' All judgments signifying 'variable longer,' no matter whether they took the form 'second (or variable) longer' or 'second (or standard) shorter,' will be reported under the heading 'variable longer.'

Table II shows the increase in the number and percentage of 'variable longer' judgments with increase in the length of the variable. When the variable possesses that length at which it is judged longer than the standard in 50 per cent. of the judgments (and, consequently, shorter than the standard in 50 per cent.), it may be termed the 'subjective equivalent' of the standard. The difference between the length of the 'subjectively equivalent variable' and that of the standard may be taken as a measure of the magnitude of the illusion.

TABLE II (l–s vs. s–l)

INCREASE IN THE NUMBER AND PERCENTAGE OF 'VARIABLE LONGER' JUDGMENTS WITH INCREASE IN THE LENGTH OF THE VARIABLE INTERVAL

Standard = l–s; variable = s–l
Length of l, constant, and the same in standard and variable, = .50 sec
Length of s, constant, and the same in standard and variable, = .08 sec
Length of standard interval (the interval in l–s) = .50 sec
Lengths given the variable interval = .40; .53; .66; .79 and .92 sec
No. of subjects = 30
No. of trials for each subject with each length of variable = 80
Total no. of judgments (30 × 80 × 5) = 12,000

Variable Interval	'Variable Longer' Judgments: Variable 2nd Av. No.	Per Cent.	Variable 1st Av. No.	Per Cent.	Total Av. No.	Per Cent.	N
.40 (sec).....	3.0 ± *.20*	7.5	5.8 ± *.68*	14.5	8.8	11.0	2,400
.53.....	8.0 ± *.86*	20.0	12.6 ± *.81*	31.5	20.6	25.8	2,400
.66.....	20.5 ± *1.10*	51.3	21.0 ± *.77*	52.5	41.5	51.9	2,400
.79.....	29.3 ± *.86*	73.2	26.4 ± *.91*	66.0	55.7	69.6	2,400
.92.....	34.6 ± *.61*	86.5	30.4 ± *.78*	76.0	65.0	81.2	2,400
Var. giving 50% 'longer' judgments.....	.655 sec		.645 sec.		.651 sec		

The figures in italics are the probable errors of the averages under which they occur. They may be changed to probable errors of distributions by multiplying by 5.5, or $\sqrt{30}$.

The general outcome of the experiment is indicated graphically by Figure 1, which shows how the percentage of 'variable longer' judgments increases with increase in the length of the variable. It will be seen that the 50 per cent. level (indicating that the variable is as often as not judged longer than the standard) is not reached until the variable attains a length of .66 sec. The difference between this length and that of the standard (.50 sec) is a measure of the constant error, or the magnitude of illusion, shown by the group as a whole.

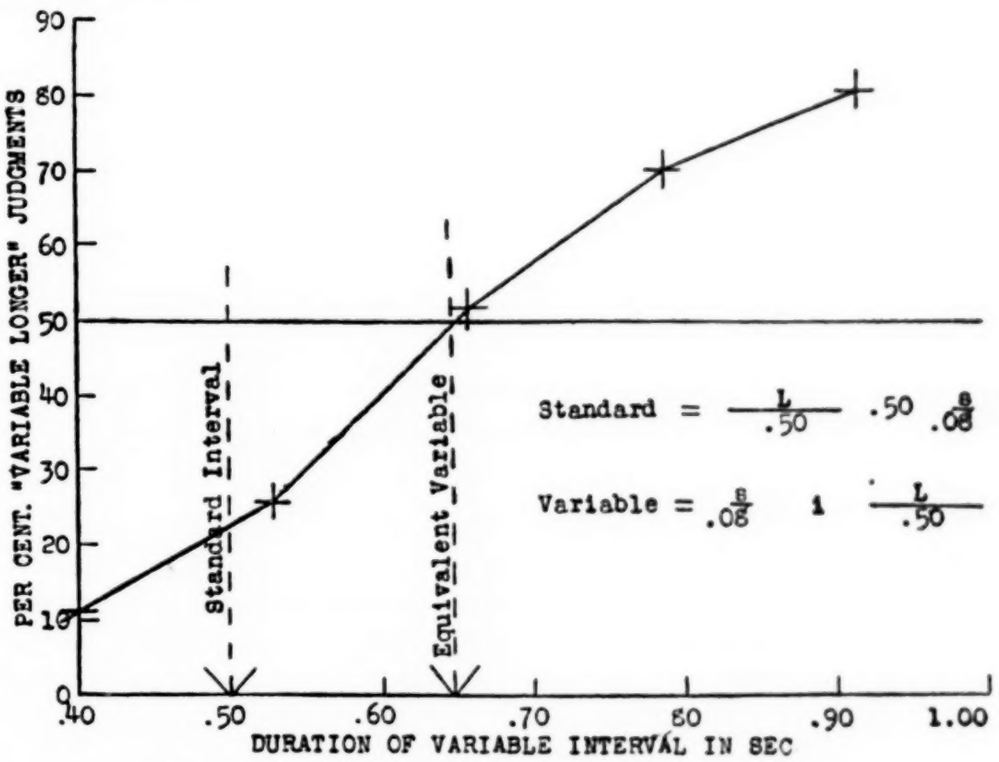

FIG. 1. Graphic representation of the data of Table II

There are various ways of calculating the magnitude and reliability of the illusion shown by the table. Since this magnitude is simply the difference between the length of the variable resulting in 50 per cent. 'variable longer' judgments and the fixed length of the standard, any method of determining that length of the variable which results in 50 per cent. of 'longer' judgments will give a measure of the illusion. One method is that of proportional interpolation. Both for the group data as a whole and for the results from each

individual the variable which is judged longer 50 per cent. of the time has been determined by simple proportional interpolation between the two percentages lying on each side of fifty. An index of the variability or reliability of the illusion is afforded by the standard deviation of the average magnitude of the illusion as shown by the various individuals.

Using various methods of calculation the following values were obtained.

1. Average of the individual 'subjectively equal' variables, each calculated by simple interpolation ..... .666 sec
   P.E.$_{dis}$ ..... .068 sec
   P.E.$_{av}$ ..... .012 sec
2. 'Subjectively equal' variable, based on pooled results of the 30 subjects, by interpolation ..... .651 sec
   Same, with variable second ..... .655 sec
   Same, with variable first ..... .645 sec
3. Length of variable giving 25 per cent. 'variable longer' judgments (by interpolation, pooled data) ..... .523 sec
4. Length of variable giving 75 per cent. 'variable longer' judgments (by interpolation, pooled data) ..... .851 sec
5. Average of variables giving 25, 50 and 75 per cent. 'variable longer' judgments[2] (pooled data) ..... .675 sec

It is obvious that, whatever values of the 'subjectively equal' variable be chosen, there exists a large constant error in the direction of an overestimation of the standard or an underestimation of the variable. Using the above value no. 1 as that of the 'subjectively equal' variable, the size of this error, or illusion, is .166 sec, or 33.2 per cent. of the length of the standard. Only one of the thirty individuals failed to show overestimation of the standard, this individual giving 50 per cent. 'longer' judgments when the variable was .06 sec shorter than the standard.[3] For the twenty-nine individuals showing an overestimation of the standard, the range of values of the variable at the 50 per cent. point was from .56 sec to .90 sec, representing overestimations of the

[2] Regarded as a useful measure by Brown and Thomson. See their *Essentials of mental measurement*, 1921, 60-61.

[3] An investigation of this illusion was conducted with five additional subjects, studied individually, by the method of minimal changes. Subject and experimenter were in different rooms. Each subject was given from ten to fourteen series of trials. Since all five subjects showed the illusion of overestimation of the interval in *l–s* compared with that of *s–l*, to a degree which harmonizes with the general trend of Table II, no special account of these experiments will be given.

standard varying from .06 sec to .40 sec, or from 12.0 to 80.0 per cent.

As a study of the effect of practice an examination was made of the results, for the entire group of subjects, on each successive one-hundred judgments. It is sufficient for this purpose to note the data obtained with the three lengths of the variable yielding nearest to 50 per cent. of 'variable longer' judgments, namely the lengths .53, .66 and .79 sec. Since these three lengths are all greater than that of the standard, the illusion manifests itself in an insufficient number of 'variable longer' judgments at these lengths. If the illusion tended to decrease with practice, the total number of 'variable longer' judgments given for these lengths would tend to increase. That this number does not increase may be seen from Table III. The figures presented in Table III therefore show no tendency for the illusion to decrease with practice, but, on the contrary, they indicate that the illusion becomes more pronounced.

TABLE III

THE PERCENTAGE OF 'VARIABLE LONGER' JUDGMENTS FOR EACH SUCCESSIVE ONE-HUNDRED JUDGMENTS

	Duration of the variable in hundredths sec							
	Variable 2d			Variable 1st			Total	
	Length of Variable			Length of Variable			Results for three	
	.53	.66	.79	.53	.66	.79	variables combined	N
1st 100.....	25	56	76	32	54	74	52.8	1800
2d 100.....	21	47	77	32	51	67	49.2	1800
3d 100.....	20	57	70	30	50	64	48.5	1800
4th 100.....	14	46	70	32	54	59	45.8	1800

The increases shown by Table III in the size of the illusion with prolongation of the experiment are statistically significant. The judgments made during the first hour of each day, *i.e.*, the judgments of the first and third hundreds of trials yield, when combined, a proportion of 'variable longer' judgments of .507 (av. of .528 and .485). The judgments of the second hours of each day, those of the second and fourth hundreds, show a proportion of 'variable longer' judgments of .475. The total number of judgments

on which each of these proportions is based is 3,600; and a calculation of the probable error of the difference between the two proportions may be made by the formula,

$$\text{P.E.}_D = .6745\sqrt{\frac{p_1q_1 + p_2q_2}{3600}}.$$

The difference in the proportions is .032, and the probable error of the difference is .008. The difference between the two proportions, being four times its probable error, is thus significant though very small. Similarly, the proportion of 'variable longer' judgments obtained the first day is reliably greater than that obtained the second day ($D/\text{P.E.}_D = 4.9$). The difference in the proportion of 'variable longer' judgments obtained the first hour of the first day and the second hour of the second day is .070, and this difference, though each proportion is based on only 1,800 judgments, is 6.4 times its probable error.

It is not likely that the increase in the illusion with increase in the number of trials is to be regarded as a practice effect. It is on the other hand very probable that it occurred, in spite of practice, as the result of flagging attention. It should be remembered that the trials were all given during two days, two-hundred trials a day. Since each one-hundred trials required an hour, the experiment entailed rather long and tedious sittings for the subjects.

There is no great difficulty in understanding how weariness and ensuing careless attention might cause this increase in the illusion, which is presumably due to the impossibility of attending to the intervals which are being compared, apart from the sounds which bound them. No matter how alert and attentive one may be, it is very difficult to 'catch' the beginning and end of these short time-intervals. The better one succeeds, however, through maintaining an analytical attitude, in grasping the intervals as such and in ignoring the sounds, presumably the more accurate will be one's reports and consequently the smaller the illusion. Just because such an abstracting attitude is too difficult to be fully attained by the subject at his best, it is all the more

susceptible to a reduction in adequacy as the subject wearies of the experiment.

The effect of the order of presentation of the standard and the variable, as shown in Table II and Figure 1, is exceedingly interesting. It is true that it matters little, so far as the size of the illusion is concerned, whether the standard or the variable be given first—the illusion being reckoned as the difference between the standard and that variable which is judged longer than the standard in 50 per cent. of the trials. The order of presentation, however, has a marked effect upon the percentage of 'longer' judgments when the variable is either decidedly short or decidedly long. The peculiar thing about the order-effect is that with a decidedly short variable, it is just the opposite of what it is with a decidedly long variable. If the variable be termed long or short according as it is longer or shorter than .66 sec, the effect upon the apparent length of the variable of giving it second instead of first may be stated as follows: If the variable is short, giving it second makes it seem shorter, whereas if it is long, giving it second makes it seem longer.

The reliability of the effect of order may be determined by calculating the probable error of the difference, in the pooled data, between the percentages of 'variable longer' judgments with variable first and with variable second.[4] Such probable errors, as well as the values of $D/\text{P.E.}_D$, are shown in Table IV. Under each proportion (p), and under each difference in proportions, as listed in the table, is given the corresponding standard deviation. Differences in proportions of 'variable longer' judgments due to temporal order are listed in the column headed '$D_{\text{2d}-\text{1st}}$.'

Table IV shows that, for the pooled results of the entire group, change in temporal position of the variable, in the case of all variables longer or shorter than .66 sec, causes a statistically significant difference in the proportion of 'variable longer' judgments (a difference varying from 5.6 to 9.8 times its probable error). When the percentages of 'variable

[4] By the formula, $\text{P.E.}_D = .6745\sqrt{\frac{p_1q_1 + p_2q_2}{N}}$.

TABLE IV

DIFFERENCES DUE TO TEMPORAL ORDER OF STANDARD AND VARIABLE IN THE PROPORTION OF 'VARIABLE LONGER' JUDGMENTS IN THE POOLED DATA OF THIRTY SUBJECTS

Length of Variable	Proportion of 'Variable Longer' Judgments: Variable 2d		Variable 1st		$D_{v2d-v1st}$	P.E.$_D$	D/P.E.$_D$
	p	N	p	N			
.40....	.075	1200	.145	1200	−.070	.0087	8.0
	.008		*.010*		*.013*		
.53....	.200	1200	.315	1200	−.115	.0119	9.7
	.012		*.013*		*.018*		
.66....	.513	1200	.525	1200	−.012	.0135	0.9
	.014		*.014*		*.020*		
.79....	.732	1200	.660	1200	+.072	.0128	5.6
	.013		*.014*		*.019*		
.92....	.865	1200	.760	1200	+.105	.0107	9.8
	.010		*.012*		*.016*		

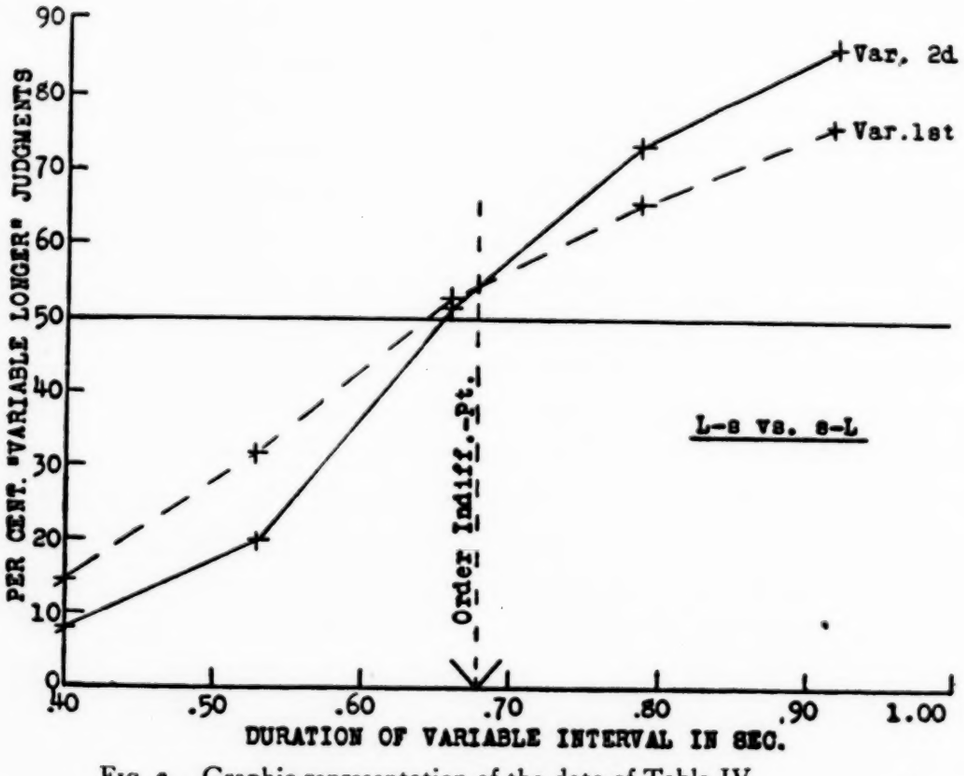

FIG. 2. Graphic representation of the data of Table IV

longer' judgments for each temporal order are plotted as curves, as in Fig. 2, it may be seen that the value of the variable at which the effect of order vanishes, the value, that is, at which the two curves intersect, is .679 sec. A simple calculation, assuming the increase in the percentage of 'variable longer' judgments between the intervals .66 and .79 sec to be proportional to the increase in the length of the

interval, yields the same value. This value may be termed the order indifference-point. Discussion of why the order indifference-point should lie at this value will be postponed until the results of the further experiments performed have been presented.

Experiments on m–m compared with l–s and with s–l. In order to obtain a better understanding of the *l–s* vs. *s–l* illusion, and also to secure a check on the results already described, further experiments were conducted in which the two sounds bounding the standard interval were of equal length. In these experiments, the standard interval of .50 sec was bounded by two sounds both having a duration of 0.29 sec. The temporal form in which this interval occurred will be designated *m–m*. With this standard, two experiments were conducted; in the one, the standard was compared with the interval in *s–l*, while, in the other, it was compared with the interval in *l–s*. In each of these experiments, the length given the two sounds bounding the variable interval was such that their combined length was exactly equal to that of the combined length of the two sounds bounding the standard. Whether the experiment dealt with *l–s* or *s–l*, *l* had a duration of .50 sec and *s* one of .08 sec. Since the duration of each of the bounding sounds in *m–m* (the standard) was .29 sec, the total duration of the sounds, in the standard and in both the variable forms, was .58 sec; and when the intervals between the sounds were equal (at .50 sec), the total duration of any of the three forms, *m–m*, *l–s*, or *s–l*, was exactly 1.08 sec. It follows that, except for the occurrence of an illusion, the subjects' judgments should reveal no discrepancy between the 'subjectively equal' and the 'objectively equal' variable. This would follow even if the subjects unwittingly failed to carry out the instruction to compare only the intervals of silence and, instead, based their judgments upon the total durations of the forms.

The procedure employed in these two experiments does not need special description, since it was in all respects similar to that which has already been described in connection with the experiment on *l–s* compared with *s–l*. It should be noted, however, that a new group of subjects was used in the present instance. It would pre-

sumably have been preferable to use the same group of subjects throughout, but this was impossible because of demands upon the subjects' time. The two groups of subjects, however, were very similar, constituting parallel sections of the same course in introductory laboratory psychology. So far as their behavior in the present experiments is concerned, there is every reason to suppose that the two groups may be regarded as similarly selected and as differing not more than two such groups might differ by chance.

The results obtained on the interval in *m–m* compared with that in *s–l* are shown in Table V. It is evident that the interval occurring in *s–l* is greatly underestimated. This is clear from the fact that when the intervals in the two forms are both .50 sec (and total durations also equal) the interval in *s–l* is judged shorter than that in *m–m* in 91 per cent. of the trials. The interval in *s–l* does not seem equal to that in *m–m* (.50 sec), *i.e.*, is not judged longer in 50 per cent. of the trials, until it is given a length of .70 sec. These

TABLE V (*m–m* VS. *s–l*)

INCREASE IN THE NUMBER (AND PERCENTAGE) OF 'VARIABLE LONGER' JUDGMENTS WITH INCREASE IN THE LENGTH OF THE VARIABLE INTERVAL

Standard = *m–m*; variable = *s–l*
Length of *m* = .29 sec; of interval in *m–m* = .50 sec
Length of *l* = .50 sec; of *s* = .08 sec
Lengths given the variable interval = .37; .50; .63; .76 and .89 sec
No. of subjects = 35
No. of trials, each subject, for each length of variable = 40
Total no. of judgments (35 × 40 × 5) = 7,000
The probable errors given in italics are probable errors of averages

Variable Interval	'Variable Longer' Judgments: Variable 2d Av. No.	Variable 2d Per Cent.	Variable 1st Av. No.	Variable 1st Per Cent.	Total Av. No.	Total Per Cent.	N
.37 (sec)...	0.6 ± *.09*	3.0	0.9 ± *.14*	4.5	1.5	3.8	1,400
.50.....	0.7 ± *.16*	3.5	2.9 ± *.22*	14.5	3.6	9.0	1,400
.63.....	7.2 ± .45	36.0	6.8 ± *.42*	34.0	14.0	35.0	1,400
.76.....	13.7 ± *.41*	68.5	11.1 ± *.53*	55.5	24.8	62.0	1,400
.89.....	15.7 ± *.30*	78.5	14.0 ± *.50*	70.0	29.7	74.3	1,400
Var. giving 50% 'longer' judgments.....	.686 sec		.726 sec		.702 sec		

facts demonstrate the existence of a very pronounced illusion, consisting in the underestimation of the interval in *s–l*, or in the overestimation of the interval in *m–m*, when the intervals in *s–l* and in *m–m* are compared with each other.

The exact amount of the illusion depends upon the precise method employed for calculation of the value of the variable at the point of subjective equality.

The following values have been calculated.

1. Average of the individual 'subjectively equal' values ..... .718 sec
   P.E.$_{dis.}$ ..... .057 sec
   P.E.$_{av.}$ ..... .010 sec
2. 'Subjectively equal' variable based on pooled results of the 35 subjects, by interpolation ..... .702 sec
   Same, with variable second ..... .686 sec
   Same, with variable first ..... .726 sec
3. Length of variable giving 25 per cent. 'variable longer' judgments ..... .580 sec
4. Length of variable giving 75 per cent. 'variable longer' judgments ..... .897 sec
5. Average of variables giving 25, 50 and 75 per cent. 'variable longer' judgments ..... .726 sec

The illusion was shown by every subject and ranged in magnitude from .083 sec to .57 sec, *i.e.*, from 16.6 to 114.0 per cent. of the standard.

Complementary to the experiment just described, dealing with *s–l*, was one performed with the same group of subjects in which the variable was the interval in *l–s*, while the standard interval remained, as before, the interval in *m–m*. The two experiments were conducted on the 'ABBA' plan, that is, between the first and last hundred trials, dealing with *s–l* vs. *m–m*, there were given the two hundred trials dealing with *l–s* vs. *m–m*. A two days' break in the total series occurred between the second and third hundreds of trials. The results obtained with the form *l–s* are summarized in Table VI.

This table shows that the interval in *l–s* has to be shorter than that in *m–m* in order to seem equal, that is, to be judged longer in 50 per cent. of the trials. By simple interpolation, the 'subjectively equal' variable, for all subjects taken together, is found to have a duration of .407 sec. It follows that the illusion, consisting in an overestimation of the interval in *l–s* as compared with that in *m–m*, has a magnitude equal to the difference between .50 and .407 sec, or .093 sec.

TABLE VI (m–m VS. l–s)

INCREASE IN THE NUMBER (AND PERCENTAGE) OF 'VARIABLE LONGER' JUDGMENTS WITH INCREASE IN THE LENGTH OF THE VARIABLE INTERVAL

Standard = m–m; variable = l–s
Length of m = .29 sec; of interval in m–m = .50 sec
Length of l = .50 sec; of s = .08 sec
Lengths given the variable interval = .24, .37, .50, .63 and .76 sec
No. of subjects = 35
No. of trials, each subject, for each length of variable = 40
Total no. of judgments (35 × 40 × 5) = 7,000

Variable Interval	'Variable Longer' Judgments: Variable 2d Av. No.	Variable 2d Per Cent.	Variable 1st Av. No.	Variable 1st Per Cent.	Total Av. No.	Total Per Cent.	N
.24 (sec)...	2.8 ± .34	14.0	6.2 ± .47	31.0	9.0	22.5	1,400
.37.....	7.8 ± .60	39.0	10.1 ± .58	50.5	17.9	44.8	1,400
.50.....	12.1 ± .44	60.5	13.2 ± .44	66.0	25.3	63.3	1,400
.63.....	15.7 ± .31	78.5	14.4 ± .49	72.0	30.1	75.3	1,400
.76.....	17.6 ± .33	88.0	15.2 ± .45	76.0	32.8	82.0	1,400
Var. giving 50% 'longer' judgments.....	.437 sec		.367 sec		.407 sec		

Various methods of calculation of the value of the interval in l–s when 'subjectively equal' to the standard interval, in m–m, give the following results.

1. Average of the individual 'subjectively equal' values ..... .410 sec
   P.E.$_{dis.}$ ..... .116 sec
   P.E.$_{av.}$ ..... .020 sec
2. 'Subjectively equal' variable based on pooled results of the 35 subjects, by interpolation ..... .407 sec
   Same, with variable second ..... .437 sec
   Same, with variable first ..... .367 sec
3. Length of variable giving 25 per cent. 'variable longer' judgments..... .255 sec
4. Length of variable giving 75 per cent. 'variable longer' judgments..... .627 sec
5. Average of variables giving 25, 50 and 75 per cent. 'variable longer' judgments ..... .430 sec

The above figures indicate only a small illusion. In fact, 6 of the 35 subjects showed constant errors contrary to the general tendency, so that this illusion must be regarded as somewhat unreliable.

The data of Tables V and VI taken together are in

harmony with those of Table II, and the two sets of data, obtained from different groups of subjects, constitute a check on each other. Table II shows the interval *l–s* overestimated in comparison with that in *s–l*, whereas Tables V and VI, as readily seen from the curves of Fig. 3, show the interval *l–s* slightly overestimated in comparison with *m–m*, which, in turn is greatly overestimated in comparison with *s–l*. On the principle that two things which are equal to a third are equal to each other, one might expect from the figures of Tables V and VI taken together that the interval in *s–l*, when .702 sec long, would seem just equal to the interval in *l–s* when the latter had a duration of .407 sec, since at these lengths each of the intervals mentioned were judged equal to the standard *m–m*. Such an expectation, however, would imply the existence of a larger illusion than shown by the data of Table II, dealing directly with *l–s* vs. *s–l*. According to the latter table, the interval in *s–l*, when about .66 sec long, seems equal to that in *l–s* when the latter is .50 sec. There exists considerable discrepancy, therefore, between the results of Table II and those of Tables V and VI, with respect to the indicated magnitude of the *l–s* vs. *s–l* illusion. This discrepancy may be due in part to the effect of order of presentation of standard and variable. It may be noted that if the results with the variable second are alone considered, Tables V and VI would indicate an illusion for *l–s* vs. *s–l* of only .686 sec − .437 sec, or .149 sec, a result which agrees very closely with that shown in Table II, with the variable second, namely, an illusion of .655 sec − .50 sec, or .155 sec. It is likely, however, that the discrepancy must be accounted for largely by the fact that the two sets of results were obtained on different groups of subjects,—a fact which, it may be noted, makes the determination of the existence and direction of the illusion all the more reliable.

The effect of order of presentation of standard and variable, as shown in Tables V and VI, is entirely analogous to that revealed by Table II. All three tables show a greater precision or keenness of judgment with the variable given second. This greater precision shows itself in the fact that with the variable in second place, when short, it seems shorter, and when long, longer. The effect of order is thus dependent upon the length of the variable. In general, the effect of order tends to disappear as the

variable reaches a certain middle or indifferent length. This value of the variable, at which the effect of order disappears, as calculated by simple interpolation from Table V, is .61 sec, and from Table VI, .56 sec.

In keeping with the effect of order is the fact that in both Tables V and VI the magnitude of the illusion is smaller when the variable comes second. When the variable is the interval in *s–l* (Table V), its length at the point of subjective equality is greater than at the order-indifference value, and consequently when at the subjectively equal length it seems longer in second place than when first. When second, the variable needs to be only .686 sec long to be judged equal to the standard; whereas, when first, it needs to be .727 sec long. Conversely, when the variable is the interval in *l–s* (Table VI), being shorter at the subjectively equal value than at the order-indifference value, it seems shorter when second, and needs to be .07 sec longer when second than when first, to be judged equal to the standard.

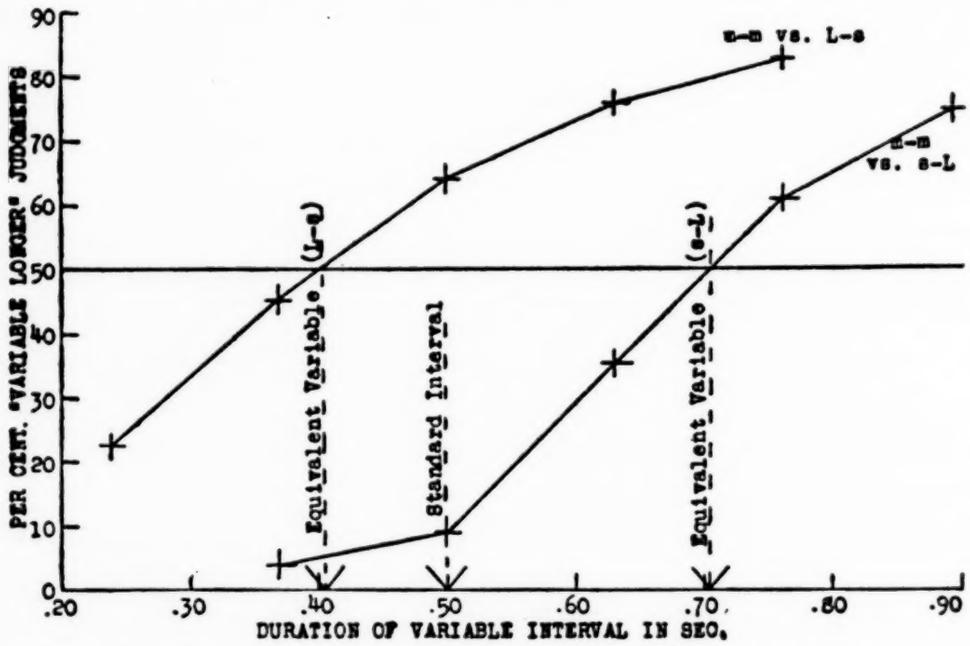

FIG. 3. Graphic representation of the data of Tables V and VI

Tables V and VI each summarize data consisting of 200 judgments from each subject obtained on two days. Such data are not as adequate for the purpose of studying the effect of prolonging the experiment as are the data of Table II on *l–s* vs. *s–l*, which are based on 400 judgments by each subject. But if the magnitudes of the illusions shown in Tables V and VI are computed separately for each day's judgments, it becomes evident in both cases that the illusion was greater on the second day. Thus the illusion of underestimation of the interval in *s–l*, as calculated from the first one-hundred judgments (by simple interpolation from the

group data), was .179 sec, but as calculated from the second one-hundred judgments was .226 sec. Similarly, the amount of overestimation of the interval in *l–s* indicated by the first one-hundred trials was only .057 sec, whereas according to the second one-hundred, it was .129 sec. Thus the data of Tables V and VI substantiate the conclusion established by the data of Table II, that the illusion grows more pronounced, presumably as the result of lessened interest and attention on the part of the subjects, with prolongation of the experiment.

The three experiments which have now been described lead to consistent conclusions regarding the effects of various stimulus-forms upon the apparent length of the intervals included therein. These effects upon the apparent length of the interval may be summarized as follows:

(1) *l–s* increases apparent length more than *m–m*.
(2) *m–m* " " " " " *s–l*.
(3) *l–s* " " " " " *s–l*.

Experiment on s–s vs. s–l. One further investigation appeared desirable, namely, one to determine the effect of the form *s–l* in comparison with that of the form *s–s*. Such an experiment was accordingly conducted, on a third group of subjects, composed of another section of introductory laboratory students. The results are presented in Table VII, and shown graphically in Fig. 4.

TABLE VII (*s–s* VS. *s–l*)

INCREASE IN THE NUMBER (AND PERCENTAGE) OF 'VARIABLE LONGER' JUDGMENTS WITH INCREASE IN THE LENGTH OF THE VARIABLE INTERVAL

Standard = *s–s*; variable = *s–l*
Length of *l* = .38 sec
Length of *s*, constant, and the same in standard and variable, = .06 sec
Length of standard interval (the interval in *s–s*) = .50 sec
Lengths of the variable interval = .28; .38; .48; .58 and .68 sec
No. of subjects = 30
No. of trials, for each subject, for each length of variable = 20
Total no. of judgments (30 × 20 × 5) = 3,000

TABLE VII—*Continued*

Variable Interval	'Variable Longer' Judgments: Variable 2d Av. No.	Variable 2d Per Cent.	Variable 1st Av. No.	Variable 1st Per Cent.	Total Av. No.	Total Per Cent.	N
.28 (sec)...	1.2 ± .09	12.0	3.1 ± .25	31.0	4.3	21.5	600
.38.....	5.3 ± .18	53.0	7.0 ± .20	70.0	12.3	61.5	600
.48.....	7.5 ± .14	75.0	8.7 ± .14	87.0	16.2	81.0	600
.58.....	8.9 ± .07	89.0	9.4 ± .09	94.0	18.3	91.5	600
.68.....	9.9 ± .02	99.0	9.7 ± .08	97.0	19.6	98.0	600
Var. giving 50% 'longer' judgments.....	.373 sec		.329 sec		.350 sec		

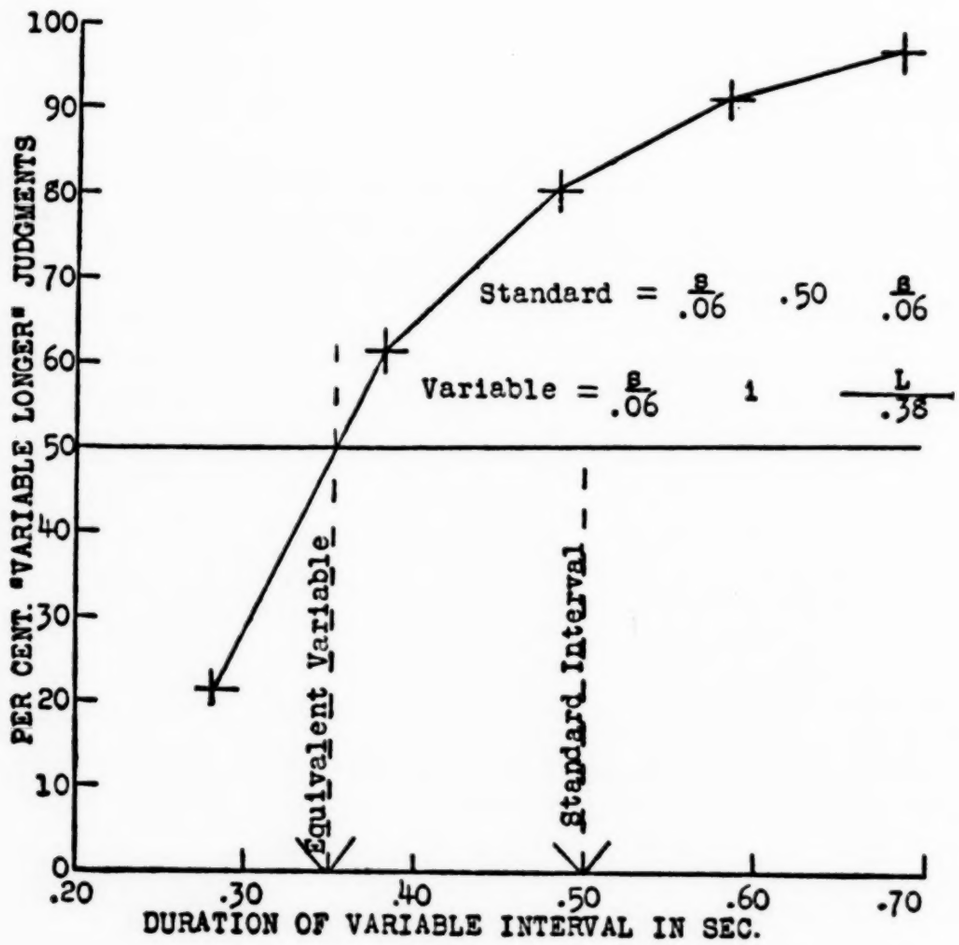

FIG. 4. Graphic representation of the data of Table VII

Table VII indicates that the interval occurring in the form *s–l* is greatly overestimated as compared with that in the form *s–s*. This is seen in the fact that the interval in *s–l*, the variable, is judged longer 50 per cent. of the trials, that is, is 'subjectively equal' to the standard, when it is actually much shorter.

Various calculations of the value of the variable at the point of subjective equality yield results as follows.

1. Average of the individual 'subjectively equal' values, each determined by simple interpolation ..... .360 sec
   P.E.$_{dis.}$ ..... .028 sec
   P.E.$_{av.}$ ..... .005 sec
2. 'Subjectively equal' value, based on pooled results, by interpolation ..... .350 sec
   (*a*) With variable second ..... .373 sec
   (*b*) With variable first ..... .329 sec
3. Length of variable giving 25 per cent. 'variable longer' judgments ..... .289 sec
4. Length of variable giving 75 per cent. 'variable longer' judgments ..... .449 sec
5. Average of variables giving 25, 50 and 75 per cent. 'variable longer' judgments ..... .363 sec

By different methods of calculation, then, the values obtained for the variable at the point of subjective equality are .360, .350 and .363 sec. It follows that there exists an illusion consisting in the relative overestimation of the interval in *s–l* by about .14 sec, or 28 per cent. of the standard. The illusion was shown by every subject.

It should be pointed out that the experiment represented by Table VII differs from the preceding experiments in several respects other than in the fact that the standard occurred in the form *s–s* instead of in either the form *l–s* or the form *m–m*. In the previous experiments the total forms, the intervals in which were compared, had exactly the same length when the intervals were equal; whereas, in the present experiment, when the intervals were equal, the total form *s–l* was much longer than the total form *s–s*. This fact may have favored any existing tendency to compare total lengths. Moreover, the sounds bounding the 'empty' intervals did not have the same length in the present experiment as in the previous ones. In the present experiment, the longer sound had a length of .38 sec in place of .50 sec, and the shorter a length of .06 sec in place of .08 sec.

The effect of order of presentation of stimulus and variable, upon comparisons of the intervals in the forms *s–s* and *s–l*, is practically identical with its effect in the preceding experiments (Tables II, V and VI). If the variable is short, the variable seems shorter, and if long, longer, when it comes second. Only one of the variables listed in Table VII is longer than .66 sec. This one is judged longer more often when it comes second than when it comes first; though there is very little difference in the frequency of the 'longer' judgments for the two temporal orders, and the difference is not very reliable, being only 2.5 times its probable error. All the other variables, varying in length from .28 to .58 sec, are judged longer less often when they come second than when they come first. In other words, these short variables seem shorter in second place than in first. The differences in the percentages of 'longer' judgments, due to temporal order, in the case of these shorter variables, are statistically reliable, varying from 5.7 to 8.6 times their probable errors. The difference is greatest and most reliable when the variable is shortest (.28 sec), and decreases both in amount and reliability as the variable grows longer, until, when the variable reaches a length of .651 sec, it vanishes. With further increase in the length of the variable the difference due to time-order reappears, but is of opposite sign.

Discussion of time-order effect. The effect of temporal order is so uniform in the three experiments which have now been described, and of such a peculiar nature, that it calls for an attempt at explanation. The effect of giving the variable second is not always an increase in the keenness of discrimination. It may be noted, for example, in Table II, that when the variable is .16 sec longer than the standard, it is judged longer less often when second than when first. It follows that, in this instance, keenness of discrimination is poorer when the variable is second. The effect of order can be truly summarized only by reference to an absolute length somewhat greater than the length possessed by the interval used as a standard in the preceding experiments. In all the preceding experiments the length of the standard interval

was .50 sec. It is not until the variable considerably exceeds this length that it is judged longer more often when second.

The length of variable at which the order of presentation of stimulus and variable has no effect, which may be called the order-indifference point, differs but slightly in the various experiments. The various values obtained for this point are as follows:

With *l–s*	compared with	*s–l*	.....	.68	sec
" *m–m*	"	" *s–l*	.....	.61	sec
" *m–m*	"	" *l–s*	.....	.56	sec
" *s–s*	"	" *s–l*	.....	.65	sec
Av.			.....	.625	sec
M.V.			.....	.04	sec

In all cases, the order-indifference point is greater than the duration of the standard, and, so far as can be seen, bears no relation to the value of the variable at the point of 'subjective equality.' While it is true in the case of *l–s* vs. *s–l* that the order-indifference value and the 'subjectively equal' value of the variable are in close agreement, there is a decided discrepancy between these values in the other three cases. In the experiment on *l–s* vs. *s–s* the order-indifference value of the variable is .65 sec, whereas the 'subjectively equal' variable is but .37 sec. It should be noted also that while the order-indifference point may possibly be affected by the range of variables used in the experiment, it is certainly not primarily determined by this range. Thus in the data of Table VII (*s–s* vs. *s–l*) there is only one variable longer than the order-indifference value, whereas in Tables II, V and VI the order-indifference value is near the middle of the range of values used. The conclusion is indicated that the order-indifference point is primarily a matter of some absolute duration. If any interval less than .625 ± .04 sec be called short, and one beyond this value long, then the effect of time-order in all four of the above experiments may be described by the statement that if the variable comes second, it is more often judged shorter when short and longer when long, than if it comes first,—irrespective of the length of the standard interval, the length of the variable when sub-

jectively equal to the standard or the range of variables used in the experiment.

Now this length of .625 sec is extremely close to that length which has been established by previous investigators as the length separating intervals giving the absolute impression of 'short' from those producing the absolute impression of 'long'; and the conclusion is hardly avoidable that the disappearance of the time-order effect at this length of interval is intimately connected with the fact that this is the length which, as regards the absolute impression, is neither short nor long.

The average length of the latter interval, calculated from the results of five previous investigators, is .63 sec, a value which differs only by .005 sec from the average value of the order-indifference point shown by the data presented above. While it is true that these previous investigators differ from each other in the terminology used to describe the absolute indifference value it seems likely that they have been investigating substantially the same phenomenon. The results they obtained may be summarized as follows:

Vierordt[5] (adequate rate)	0.64 sec
Schumann[6] (rate permitting adequate adjustment of attention)	0.60 sec
Katz[7] ('angenehm'—lying between the categories of 'short' and 'long')	0.60 sec (.55–.65 sec)
Schultze[8] (range of intervals showing 'subjective Einheitlichkeit')	0.66 sec (.44–.88 sec)
Benussi[9] (undecided—as between 'long' and 'short')	0.65 sec (.58–.72 sec)
Av.	0.63 sec

The peculiar effect of order of presentation of standard and variable is not completely explained simply by the assumption that it is related to the absolute impression. The matter is complex, and two further assumptions appear necessary. The first of these is that the absolute impression made by the variable is more pronounced when the variable comes second than when it comes first. It would then follow that the variable if 'absolutely' short, would seem shorter

[5] K. Vierordt, Der Zeitsinn nach Versuchen, 1868, 19.

[6] F. Schumann, Ueber die Schätzung kleiner Zeitgröszen, *Zsch. f. Psychol.*, 1893, 4, 59.

[7] D. Katz, Experimentelle Beiträge zur Psychologie des Vergleichs im Gebiete des Zeitsinns, *ibid.*, 1906, 42, 314.

[8] F. E. O. Schultze, Beitrag zur Psychologie des Zeitbewusstseins, *Archiv. f.d. ges. Psychol.*, 1908, 18, 275–351.

[9] V. Benussi, Psychologie der Zeitauffassung, 1913, 16.

when second, and if 'absolutely' long, longer when second, as is actually the case. The second assumption needed is that the absolute impression made by the variable has more influence upon the ensuing judgment than the absolute impression made by the standard. The latter, it may be noted, never varied in length, and, while 'absolutely' short, was not so to any pronounced degree.

General summary and explanation of illusions. The effect of time-order of standard and variable, which has been set forth with some fullness, should of course not be confused with the far greater effect exerted by the sounds bounding the intervals. The fundamental illusions which have been described above are not due to time-order, but to the nature of these bounding sounds. The effect of the former is so slight that it can be demonstrated with reliability only by the use of the large numbers yielded by the pooled judgments of an entire group of subjects; whereas the illusions due to the durations of the sounds limiting the intervals are revealed by the few hundred judgments of nearly every one of the individual subjects, these judgments being treated so as to eliminate the effect of time-order. The general outcome of the present study as regards these fundamental illusions may be represented in a small table (Figure 5) showing, for each of the four experiments which have been described, the nature of the standard used and the corresponding equivalent variable.

Table	Standard	Equivalent Variable	Illusion
II	$\frac{l}{.50}$ .50 $\frac{s}{.08}$	$\frac{s}{.08}$ .67 $\frac{l}{.50}$	l-s > s-l
VI	$\frac{m}{.29}$ .50 $\frac{m}{.29}$	$\frac{l}{.50}$ .41 $\frac{s}{.08}$	l-s > m-m
V	$\frac{m}{.29}$ .50 $\frac{m}{.29}$	$\frac{s}{.08}$ .72 $\frac{l}{.50}$	m-m > s-l
VII	$\frac{s}{.06}$ .50 $\frac{s}{.06}$	$\frac{s}{.06}$ .36 $\frac{l}{.38}$	s-l > s-s

FIG. 5. Schematic summary of all experiments

In general, the fundamental illusions brought to light may be summarized as follows. If we take as a starting point an 'empty' interval between two short sounds, the first of which is called the initial sound and the second the terminal sound, then:

(1) Lengthening the terminal sound causes the interval to be judged longer (as is evident from Table VII showing the interval in *s–l* to be overestimated in comparison with that in *s–s*),

(2) Lengthening the initial sound causes the interval to be judged longer (as is evident from Table II, showing the interval in *l–s* to be judged greater than that in *s–l* and also from Tables V, VI and VII, which, taken together, show that the interval in *l–s* is overestimated in comparison with that in *s–s*),

(3) Lengthening both initial and terminal sounds likewise causes the interval to be judged longer (as is evident from Tables V and VII, which, taken together, show the interval in *m–m* to be overestimated in comparison with that in *s–s*), and

(4) The effect of a long initial sound, in causing the interval to be judged longer, is decidedly greater than that of a long terminal sound (as is evident from Table II showing the interval in *l–s* to be overestimated in comparison with that in *s–l*, and also from Tables V and VI, which, taken together, show the same thing).

A theoretical explanation of these illusions is not difficult. Being obviously due to the sounds bounding the intervals, it is only necessary to assume, as anyone may readily verify for himself, that it is difficult to 'catch' the interval, as such, to the neglect of the sounds. The demands in the way of an analytical or abstracting attitude are too great. It is entirely impossible to listen to the interval without also paying some attention to the limiting sounds. One's reaction is to some extent always a reaction to the temporal form as a whole. It thus happens that one gains an impression of total length, with the knowledge that there was an interval, but no very accurate impression of its separate length. The impression

of total length influences the judgment of the length of the interval because the two are not sharply discriminated; they are reacted to separately only to a degree. The reason why a long initial sound influences the judgment more than a long terminal sound, is presumably because it is more difficult, for one who is attempting to judge the interval, to ignore the initial than the terminal sound. One cannot escape the initial sound because one has to 'catch' its ending in order to apprehend the beginning of the interval. Throughout a long initial sound, therefore, one is attentively waiting for its end. On the other hand, the instant the terminal sound begins, no matter what its length, the observer can turn his attention away, as the interval is then complete. No attempt is here made to offer a theory as to the processes constituting the reaction to an 'empty' interval, that is, a theory of the nature of the time experience as such; but the nature of one's theory of the fundamental processes involved in attending to an 'empty' interval does not affect the above explanation of the effect of the limiting sounds upon the judgment of the length of the interval.

Put very simply and in somewhat more physiological terms the explanation offered of the illusions described above is as follows: Long limiting sounds exert an inhibiting effect upon those processes (whatever they may be) which constitute one's reaction to an 'empty' interval. This inhibition is greater when the long sound precedes, than when it follows, the interval. In other words, the inhibition exerted by the long sound is greater when anterograde than when retrograde.

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THE CONCEPT OF THE THRESHOLD AND HEYMANS' LAW OF INHIBITION

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II. Correlation of the Visual Threshold and Heymans' Coefficient of Inhibition in a Single Individual, with uniocular Vision

In the first paper of this series [1] the hypothesis of Heymans stating that the simple threshold is almost wholly if not exclusively due to the continuous inhibitory influences in the extra- and intraorganic environment was described and the facts and arguments supporting his view were reviewed. The confirmation of his results by one of us (Spencer) for individual variation with a stimulus of constant quality under binocular observation was reported and was accompanied by a discussion of the assumptions underlying Heymans' hypothesis. Among these assumptions was noted the implication that, for a single subject, the threshold for a given type of visual stimulus should vary directly with daily variations in the susceptibility to inhibition by a neighboring stimulus. The present report is concerned with an investigation of the validity of this assumption.

Certain changes in the apparatus used in preceding studies were made in order to verify the relationship when the threshold stimulus and the inhibitory stimulus were each visible to one eye alone. The subject sat in a dark room, facing one wall through which the lights were presented. The visual field was completely dark except for these stimulus apertures. Three apertures were used, each one cm in diameter. As viewed by the subject the left aperture, of circular shape, revealed the passive stimulus by which thresholds could be measured, through the reduction of the intensity by a fixed, black glass filter and adjustment of a slide photometer behind the aperture. The inhibitory stimulus was presented through the second aperture, also circular in shape, 6.25 cm to the right, and on the same horizontal line. A fixation object consisting of a symmetrical cross 1 cm in each dimension with the cross arms 1 mm wide formed the third aperture, 6.25 cm to the right of the inhibitory stimulus. A screen

[1] This Journal, 1928, 11, 88–97.

was erected perpendicular to the end of the photometers and extending to the eyes, 110 cm away, which prevented the inhibitory stimulus from being seen by the left eye or the threshold stimulus from being visible to the right. A slot was cut lengthwise in this screen so that the fixation cross could be seen by both eyes but without permitting either of the other two aperatures to be seen by more than one eye. The cross was illuminated from the rear by a weak light of constant intensity filtered by a piece of ruby glass. In as far as the cross acted as an inhibitory stimulus its effect was minimized by its weakness and hue, and moreover remained constant throughout all observations. The threshold and inhibitory stimuli were both 40-watt Mazda lamps shining through milk glass, with the addition, in the case of the threshold stimulus, of the black filter glass mentioned above. Intensities of the two variable stimuli were read in arbitrary units from the inverse square scales of the photometers. The subject was dark adapted for a period of 15 min before the beginning of the determination of the thresholds.

The use of a single subject as indicated in the problem has the special advantage of developing, as the experiment proceeds, a reactor of specific and continuous experience with the conditions and requirements of procedure. The practice error, which, as was noted, was not allowed for in the experiment reported in the preceding paper of this series, therefore diminishes as the experiment continues and can be estimated to a certain degree by correlational methods. It was possible, moreover, to obtain from the subject reports upon daily freshness, hours of sleep, etc, on a reasonably comparable scale from day to day, so that further insight into the determination of particular threshold values might be had. The result of these incidental measures will be dealt with in a subsequent paper.

The psychophysical procedure used was again the Method of Constant Stimuli combined with the Method of Minimal Changes; the threshold being defined as the least value correctly reported in 80 per cent. out of either 10 or 20 trials. The three measures previously taken were again made in the present study, viz., the simple threshold, t_0; a threshold raised by the presence of an inhibitory stimulus A, t_A; and a second raised threshold, $t_{A'}$, obtained with A equal to twice the intensity used in obtaining t_A. The thresholds were obtained in the order given and further modification in technique was introduced by giving an extra set of 10 trials before accepting the threshold in the case of $t_{A'}$ and then returning for 10 more trials, first to the value previously twice failed for t_A and then to the value previously twice failed for t_0. Usually the additional trials resulted in no change in these thresholds; whenever the criterion of 80 per cent. correct was met in the second set of trials the threshold value subsequently determined was accepted as the true value. Each threshold, then, was determined only after three sets of 10 trials each had failed to produce 80 per cent. correct responses in any one set of 10 at a given intensity of stimulus.

A surprising amount of variation was found in the threshold from day to day. With a mean value of 29.8 stimulus units the σ for 50 days was 7.244 with a range from 13 to 44. As the nature of the scale provides a true zero value of intensity at zero on the scale (infinity) it will be seen that the sensitivity on occasion was over three times that of the lowest determination.

The close relationship reported by Heymans and confirmed for individual variation in the previous paper is again evident in the results of the present experiment. Three correlations may be given to exhibit the closeness of the relation. The threshold may be correlated with the susceptibility to inhibition by A as measured by the increase from t_0 to t_A. Let the ratio of this increase to the value of the stimulus A be called k. A second correlation may be calculated between the values of the stimulus threshold and the increase from t_0 to $t_{A'}$. Let the corresponding ratio to A' be called k'. A third correlation is possible, although in part dependent on the previous two, between t_0 and the average or sum of k and k'. The raw product moment coefficients obtained by these comparisons are as follows:

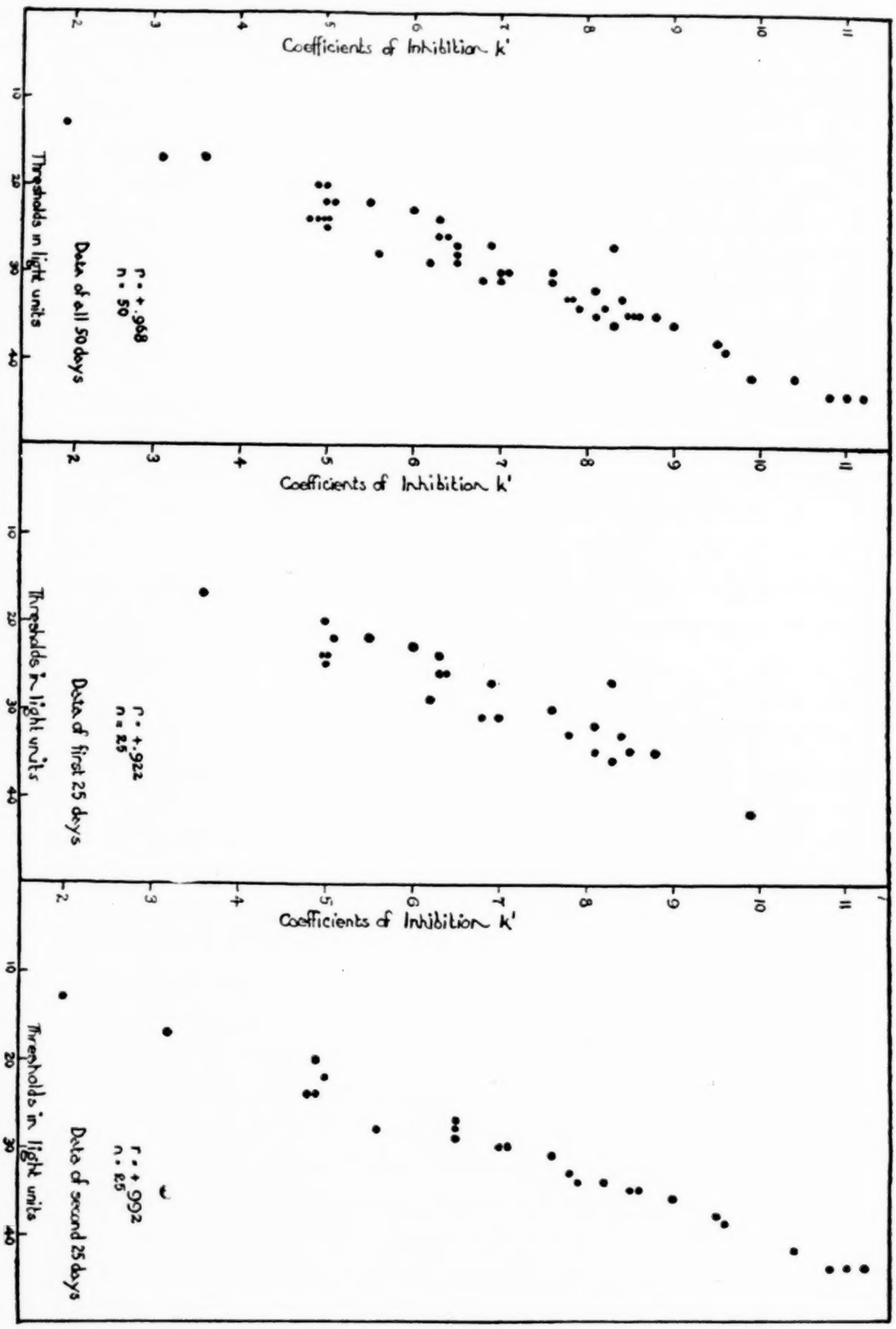
Comparison	r	P.E.$_r$
t_0 and k	.955	± .0084
t_0 and k'	.968	± .0060
t_0 and $k + k'$	.966	± .0064

A plot of the scatter for the correlation between t_0 and k' will be found in the accompanying plate. A comparison of the first two coefficients with the corresponding rs of the previous paper (.894 and .919) discloses a marked increase in the relationship connoted. It does not seem unreasonable to attribute this increase to two factors; first, to the greater accuracy and control of error in the present technique, and, secondly, to the better coöperation and constancy of error obtainable from a single subject than from fifty individuals. A further point to be noted in the comparison of the present and the preceding coefficients is the agreement of the two in showing a higher relationship for $r_{tk'}$ than for r_{tk}. It seems plausible to attribute this to several factors making for a slightly more reliable measurement in the case of k'. For example, measurements were made in determining the various thresholds only to the nearest unit, and the threshold is defined as being somewhere below t and above $t - 1$. This purely mechanical error affects k to twice the extent that k' is affected, for while σ_k is approximately equal to $\sigma_{k'}$ the coefficient $k = \frac{t_A - t_0}{A}$ and $k' = \frac{t_{A'} - t_0}{A'}$ and A' is twice as

great as A. This is another way of saying that r_{tk} was calculated from data having half as many class intervals for k as occurred for $r_{tk'}$ and k'.

The separation of the two stimuli whose physiological interaction is under consideration makes it clear that the close relationship obtained cannot be attributed to any physical interference or retinal overlapping, for the retinal fields had no elements in common except the red fixation-cross. Whatever connection is made between the two stimulations must be of central origin. The use of the uniocular presentation, therefore, constitutes a further evidence of the central nature of the threshold determination, a support which has not been given by the experiments of Heymans or Spencer up to the present time.

It was pointed out in the previous paper that a simple ratio between the values of the threshold and the corresponding coefficients of susceptibility to inhibition is required by the hypothesis proposed by Heymans. Both for his data and for the data obtained in this laboratory, however, a regression equation containing a constant additive term is a better fit than a simple ratio; the constant terms amount to 23.2 per cent. and 14 per cent. of the respective mean threshold values obtained. In the present investigation the regression equation for $r_{tk'}$ is $t_0 = 3.48k' + 5.17$. The constant term is 17.4 per cent. of the mean threshold value, 29.8 units. The distribution of thresholds and ks is noticeably less skewed than in the two previous correlations. While the appearance of a constant term of such small amount in any single study is perhaps hardly significant, the regular recurrence of such a term in each of three separate studies makes it difficult to suppose that these terms are due merely to an experimental error of observation or to sampling. The presence of some factor determining the absolute value of the threshold, but varying very little or not at all, in addition to the factor of susceptibility to inhibition, begins to look assured. The error introduced in prediction by disregarding this constant term is small. The P.E.$_{est.\ t}$ from the regression equation


Coefficients of Inhibition k'
Thresholds in light units
Data of all 50 days
r = +.968
n = 50
Coefficients of Inhibition k'
Thresholds in light units
Data of first 25 days
r = +.922
n = 25
Coefficients of Inhibition k'
Thresholds in light units
Data of second 25 days
r = +.992
n = 25

containing a constant term is ± 1.224, while the P.E.$_{est.\ t}$ from a simple ratio (M_t/M_k) is ± 1.577.[2]

It has been mentioned that the use of the same subject throughout results in a practice effect, which, while in itself disturbing, may be utilized to render the results more reliable. Practice effects are generally characterized by diminishing returns so that in most curves of learning the later part of the curves shows relatively little variation from trial to trial. In the present instance, we are very much interested in obtaining measures which vary from day to day only by reason of internal conditions and which are not progressively or otherwise disturbed by the mechanical conditions of experimentation. The observations made during the latter half of the experiment should therefore be expected to exhibit greater reliability and a less distorted picture of the true variations and relationships present in the actual behavior in which we are interested. For this reason the results obtained during the first 25 days and those obtained during the second 25 may be separately investigated with the expectation that those of the second half will present truer pictures of the facts. Below are given the correlations obtained by this division and the second two scatter diagrams of the figure represent the detailed distribution of the cases.

COEFFICIENTS OF CORRELATION BETWEEN t AND k' FOR THE TWO HALVES OF THE EXPERIMENT

	r	P.E.$_r$
First 25 days	.922	± .020
Second 25 days	.992	± .005

The great improvement in the closeness of the relationship from the first 25 days to the second is striking. With the nearer approach of the coefficient to 1.00 the persistence of the constant term is of interest. The regression equation for the second half of the experiment is $t_0 = 3.4186\ k' + 6.06$, which still contains a constant term, 19.4 per cent. of the mean threshold for the 25 days, 31.24. The suggestive regularity with which such terms occur has already been discussed.

[2] For a formula for this calculation see previous article, footnote, p. 93.

The occurrence of so high a coefficient of correlation between two variables obtained in a strictly experimental psychological investigation requires, the writers feel, a detailed statement of procedure and working habits so that every possibility of criticism of technique may be afforded.

The subject (Cohen) remained throughout the experiment in total ignorance of the regression equations or ratio of the means which might enable him to forecast for a given threshold what the values of the corresponding raised thresholds should be to maintain or improve the correlation. He was aware of the relationship being obtained; but it is difficult to see how this qualitative information could have enabled him to produce close-fitting values for k, even if he could have controlled his threshold-values as he chose. This control, however, it would seem, was also impracticable. While he was told at the conclusion of each set of ten trials to what intensity he was responding, this information was given only after the threshold was nearly arrived at, *i.e.*, when the percentage of correct responses was approaching the critical value. Even this information was withheld especially in the case of $t_{A'}$ during many sittings and almost without exception during the latter half of the experiment. Most important of all, however, it seems that the method (constant stimuli) makes it impossible for the subject to control his liminal determinations. The presentations, an equal number of "present" and "absent" cases in random and ever-changing order, were of course unknown to the subject except as he actually saw the stimulus light.

The experimenter (Spencer) was aware of the regressions, particularly of the ratio of the already existing means. To force the subject, even unconsciously, to exhibit thresholds agreeing with such a regression by the ratio was impossible. The presence of the constant term in every investigation shows the tendency of k to regress on t at an angle other than that defined by the mean ratio. Again and again the procedure had to continue, stimulus unit after stimulus unit, to the exasperation of the experimenter and yet with hardly an exception the results agree in a close correlation. Moreover, since the procedure was stereotyped and the exposure mechanical and automatic, it is difficult to see how any attempt, conscious or unconscious, on the part of the experimenter or subject, could have succeeded in determining the exact unit, or even the neighborhood of the unit, where the percentage of success would fail to reach the critical 80 per cent. In view of these considerations and the regularity with which such correlations are obtained both by us and by Heymans it does not seem likely that the essential relationship—or to any large extent the actual degree of such relationship—can be attributed to experimental bias on the part of those participating in the experiment.

Attention may again be called to the fact that the correlations reported from this laboratory in the previous and present articles do not follow necessarily from the correlation reported by Heymans. His correlation of .98 between t and k is based on the variation of t and k for a single individual as the character (hue) of the light was varied. The occurrence of correlations between t and k when the stimulus is constant in character and (1) variation is among individuals, (2) variation is of the same individual on different days, and (3)

when observation is restricted to a single eye for each stimulus used is not to be directly deduced from Heymans' results. It is only from the generalization suggested by Heymans that these last correlations follow from the first. The fact that such correlations are found, and are of the same high order, suggests that the relationship is not an artifact of the experimental conditions but a real and general fact supporting the hypothesis tentatively induced by Heymans from his limited data.

Summary

In further support of the generalization suggested by Heymans that the threshold is almost wholly if not exclusively determined by inhibitory influences in the external and intra-organic environment, new correlations between the threshold and susceptibility to inhibition in vision are reported, this time concerned with daily variations for a single individual with the character of the stimulus light held constant. These correlations are of the order of .955 and .968 for 50 cases.

When the results are divided into groups of the first 25 days and of the second 25 days, the two resulting correlations are .922 and .992. This increase in r is attributed largely to the diminished influence of the practice error in the latter half of the experiment.

The large variability in the value of the threshold found for the single subject during the 50 days, amounting to over 200 per cent. gain of the highest over the lowest on a scale having a known absolute zero, seems of general psychophysical interest.

The present study also extends the existing data on Heymans' generalization to include the case where the threshold stimulus falls upon one eye and the inhibitory stimulus falls upon the other. A constant term again appears in all the regression equations and its regular occurrence is considered suggestive.

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COMPARATIVE BEHAVIOR IN SOLVING A SERIES OF MAZE PROBLEMS OF VARYING DIFFICULTY

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A. Motor Space and the Maze

Visual space and tactual space are well recognized fields for psychological experiment that have long been intensively worked upon. Kinæsthetic space differs from these in being dependent for its exploration upon successive rather than on synchronous experiences. In the kinæsthetic experience the receptor either moves and thus touches certain points one after the other or else it makes certain movements or changes in the direction of movement in order to grasp the spatial situation. The process of acquiring spatial experience when there is no antecedent preview has, in the nature of the case, to be exploratory. Not necessarily 'trial-and-error'. The experience is more literally *trial-and-trial.* It proceeds in various directions, at various speeds, and in various sequences, leading toward comprehension of the particular spatial situation in question.

The stylus-maze used under blindfold conditions provides a typical experimental opportunity for the experiencing of motor space. At the beginning of a given experiment, the individual meeting the situation for the first time can have only the vaguest idea of the spatial area or pattern with which he has to work. He is able to assume nothing more about the maze than that it *is* a maze and that it is placed within reach of his arm on the tabletop before him. More than this, *i.e.*, the actual maze pattern, he has to learn bit by bit as he traverses it with the stylus. When he fully

[1] This problem was begun at the suggestion of Professor W. R. Miles. His constructive criticisms throughout the progress of the experiment and the coöperation of those students who acted as subjects are gratefully acknowledged.

understands the various parts and their relationships he has *learned* the maze; that is to say, he has built up a motor coördination-system involving hand and arm, one that has been proved correct by its repeated matching with the pattern of paths in the maze.

In most cases the learning or development of accurate comprehension of the spatial relations involved in the given problem requires many trials. Learning in this sense has been accomplished when the maze is finally traversed without error. Variations in the problem may be introduced by rotating the maze into different positions, *e.g.*, 90° or 180° from the original placement. The question is now whether the task will seem new and more difficult.

In the elaborate study by Perrin,[2] using adult subjects and the modified Hampton Court stylus maze, rotations of this kind were tried after the original learning. In general, very little disturbance in progress was found to result from the modifications. There was consciousness of different arm-positions for executing the various turns; but aside from the resultant sense of awkwardness, the old motor-space habit still served. This was true even when the maze was rotated while the subjects were in the act of tracing it. It would appear from these results that in order to present a series of motor-space problems of this kind, a series of unlike maze-patterns would be required. Since the kinæsthetic learning of a single pattern usually requires considerable time (frequently an hour or more and from five to seventy-five trials), the comparison of several such patterns on this basis would be a tedious performance.

B. Space Problems with the Two-Story Maze

1. *Apparatus and method.* Professor Miles [3] has described a new type of maze that lends itself very well to the examination of motor space and the ability of subjects to manipulate spatial relations. This apparatus makes possible the investi-

[2] F. A. C. Perrin, An experimental and introspective study of the human learning process in the maze, *Psychol. Monog.*, 1914, 16 (no. 70), 1–97.

[3] W. Miles, The two-story duplicate maze; tracing the stylus maze with a maximum of indirect visual guidance, this Journal, 1927, 10, 365–377.

gation of single problems and also of series of motor-space problems with the same spatial pattern presented in various positions. It is quite unnecessary for the subject to learn the pattern in order to solve the problems. The new device is called the two-story duplicate maze.

The reader is referred, for a full description of this apparatus, to the article cited. The duplicate maze is a combination of two identical mazes each 20 cm square set one directly above the other, so that the top one may be seen while the lower is being traced by the hand but out of view. The situation is one in which indirect visual guidance is made possible. The subject cannot see his hand tracing the path with the stylus; but he can look at a copy of the pattern that is being traced. The problem involved is like mirror-drawing in that the subject does not have to learn the pattern in order to trace it. Mirror-drawing presents a difficulty in motor adjustments due to the inversion of the space pattern in one axis by reflection. The two-story maze may present a still greater gap in the usual process of eye-hand coöperation, for here the eye cannot, as in mirror-drawing by reflection, see the hand at work. The hand is completely concealed by the position of the upper maze; but the maze pattern is repeated within view and may be followed out visually and tactually with one hand while the other hand works out the invisible problem below. If the pattern for the concealed hand is in a different position (rotated or inverted) from that open to view, the problem may be more difficult.

The mazes are cut from metal sheet 3 mm thick and the paths and divisions are 6 mm wide. The top maze is fixed on the lid of a box while the lower one fits on four posts carried on a metal disc which rests on the floor of the box and may be revolved. The height of the box between the mazes is about 11 cm. The sides of the box are cut away so that the subject's hand can work in this vertical clearance and the experimenter can watch the hand from the opposite side. All of the angles of this particular maze pattern are right angles. The true path is about one meter long; it passes through eight chief openings, and makes about 25 turns. In every case except one, that of 'opening 5,' the direction of progress is away from the center where the start was made.

On the top of the box in the corner, at the subject's upper right is a copper disc 7 cm in diameter (F in the Miles description) bearing an aluminum replica of the center of the maze. This disc with the little replica or 'key' can be turned, as also the lower maze can, to any desired point. It cannot, however, be inverted. When turned to positions like or corresponding to those of the lower maze it serves as an indicator of the latter's position, *i.e.*, it suggests in which direction the first move should be made. A dull-pointed stylus is used to trace the upper maze. For the lower maze a pencil is used and the path taken is thus marked on the record sheet placed between the maze and the supporting disc. A stiff round rubber guard fitted to the pencil prevents the subject's fingers from touching the maze walls.

2. *Instructions and procedure.* The subject is seated in a favorable light before the two-story maze.[4] The two mazes

[4] A 3-inch strip of black cardboard was attached to the side of the top of the box, lengthening it toward the subject to insure the invisibility of the lower maze, and of the subject's wrist and hand.

are shown, attention is drawn to their identity in size and form and their relation in position. The 'key' is also described and its special function noted as an indicator of the position of the lower maze in any given problem. The essentials of the maze problem in general (*i.e.*, reaching a goal), and of this problem in particular (*i.e.*, reaching the last exit by looking at the top maze) are briefly stated. The subject is asked to read the following suggestions which are then orally emphasized.

"Move both pencils (above and below) out through the exits *as quickly as possible*. The time you take from start to finish is kept account of.

"Follow the paths and be sure to keep *both pencils moving together*. Don't let one get ahead of the other or you may get lost.

"If you should get lost and think you would gain time by a *fresh start*, ask to be returned to the center and begin again. But remember that the time is kept continuously from your first start.

"Use the little 'key' as a *clue to position* and use any other (mental) clues that occur to you."

The two pencils are then placed in the start (center) position on both of the mazes, above and below. The pencil on the lower maze is placed in the subject's right hand, the upper in his left (or the reverse, if the subject be left-handed). Time is taken by stop-watch from the signal 'go' until the subject reaches the exit with both pencils; if he fails to get out within 15 minutes he is permitted to give up, should he so desire. At the close of each experiment in the series a new record-paper is inserted, the lower maze (and correspondingly the key) is changed to a new position, and the subject is instructed as to this proceeding by a standard formula. During the period of approximately 1½ min between experiments the upper maze still remains uncovered and visible to the subject as during the experimental period and it may therefore be studied. This possible use of the intermission is not suggested by the experimenter. At the close of the series (consisting usually of five problems) the subject is asked to make a statement of that part of the procedure which the examiner could not observe. He is asked to tell from the beginning how he solved the problems, what he thought of as good ways to go about them, what he remarked as to their character and the reasons for his successes or failures. The replies are in general simple straight-forward statements indicating, although crudely, the kind of motor-sensory activity of which he was aware and the imagery and reasoned method (if any) employed.

The completed record for each subject includes (1) a statement of time, from start to exit (or failure) for each problem, (2) a detailed account of the behavior of the subject during the experiment, with special reference to method as far as observable and to the kind of errors, and (3) a simple report by the subject given at the close of the five problems (or less, if the full series was not completed).

The entire experiment for each subject is completed at a single sitting and lasts one-half hour or less.

C. Comparative Results on Five Motor-Space Problems

1. *The problems.* Sixty-seven university students, members of a class in elementary psychology, served as subjects. The five problems in the series involved the same maze-pattern. They may be best described or identified as five different or changed positions of the lower maze. The upper maze remained fixed throughout the experiment.

The positions of the lower maze were as follows:

Prob. 1: 0°; the lower maze unrotated in register with the upper one;

Prob. 2: 180°; the lower maze rotated one-half turn (in tracing the two mazes the movements would be exactly opposed);

Prob. 3: 90°; a one-quarter turn of the lower maze in the clockwise direction (the movements of the hands in tracing the two mazes would now be at right angles to each other);

Prob. 4: 0°; reversed, *i.e.*, turned over on its face, the positions of top and bottom (0° and 180°) exchanged so that a movement away from the subject in the top maze is matched by a movement toward the subject in the bottom maze, but movements toward the left or right would be unchanged and in the same direction in both;

Prob. 5: 90°; reversed, a quarter-turn in the clockwise direction and then turned over on its face, the part that had been near 180° on the disc exchanged for 0° (as in Prob. 4) in being turned upside down but like Prob. 3 in being rotated one-quarter turn clockwise.

Time scores. The average time and S.D. in seconds for each position for the total group of subjects is given in Table I.

Table I

Average time required to solve each of five motor-space problems on the two-story maze

Space Problem	Ave. Time (sec)	Standard Deviation (sec)
Prob. 1. 0°	96	92
Prob. 2. 180°	361	311
Prob. 3. 90°	463* (475)	257
Prob. 4. 0°	217* (225)	179
Prob. 5. 90°	432* (480)	298

Average of a part of the group only. The subjects for whom no time record was available (3 for Prob. 3, 8 for Prob. 4, and 12 for Prob. 5; marked *) were with one or two exceptions those who were so slow on the earlier problems that they did

not reach the later problem or problems at all, because of the time limit. The score of 15 minutes was used for those who gave up after an unsuccessful trial lasting 15 minutes. It is obvious that the last three averages are thus too low as measures for the entire group and in comparison with the first two. Computed corrections are given in parenthesis.

2. *Time scores and logical order of difficulty of the problems.* The obtained time-scores for the individual subjects are shown plotted in Fig. 1. The histograms of this figure, as well as the average time-scores indicate that, judged by the time requirement, the five problems, when presented in the particular serial order used, range, in difficulty for the group as a whole, from easiest to hardest in the order 1, 4, 2, 3, 5.

A glance at Table II, where the time scores for fast, medium and slow workers are compared, shows that the order is not the same for these three groups. The slow workers find the difficulty ranging in the order 1, 4, 5, 2, 3; the medium workers, 1, 4, 3, 2, 5; and the fast workers, 1, 2, 4, 3, 5. Only a comparison of the problems in which the effect of practice is entirely eliminated could prove what is in fact the actual order of difficulty.

TABLE II

COMPARATIVE RESULTS (IN SEC) OF THE FIVE PROBLEMS FOR GROUPS OF FAST, MEDIUM AND SLOW WORKERS

Subjects	I	II	III	IV	V
5 fastest	24	123 (147)	419 (566)	143 (709)	677 (1386)
7 medium	95	402 (497)	349 (846)	268 (1114)	504 (1618)
8 slowest	241	463 (704)	528 (1232)	327 (1559)	426 (1985)
Total group	96	361 (457)	463 (920)	217 (1137)	432 (1569)

The figures in parentheses show the total time that the subject has worked at the end of a given problem.

It is possible that the order of difficulty in any series would actually differ for different persons, or, for groups of persons, because of their differing imagery and their motor-sensory equipment. The results of the present experiment can only suggest that this is the case. Table II seems to indicate the operation of a simple time factor in changing the order of difficulty. The fast workers, in approaching each of the problems beyond the first, have spent considerably less time in actual work on the maze than have the medium workers, and the latter have spent less time than the slow workers. And so 'learning,' in the sense of kinæsthetic acquaintance with the spatial pattern, is less completely developed in the faster workers. The order of difficulty in the case of the fast workers probably comes nearest to giving a measure of the logical order of difficulty of the problems in themselves. The order of the slowest group is probably most affected by kinæsthetic learning, and therefore the farthest from being an order of difficulty of the five maze-positions.

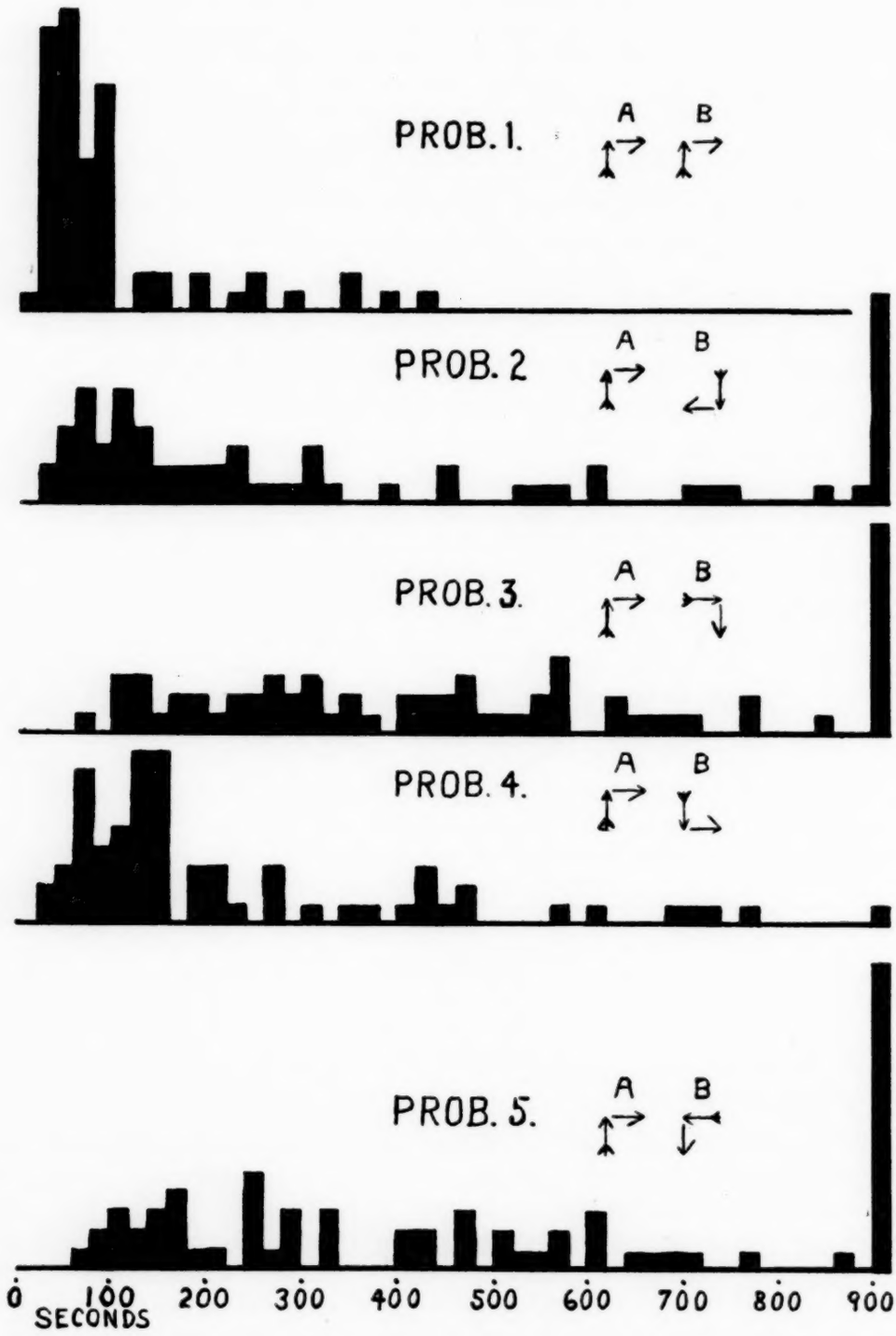

FIG. 1. Distributions of time scores for 67 subjects on five motor-space problems. The position of the upper maze is for each problem indicated by the two arrows below *A*. The position of the lower maze is similarly indicated below *B*.

Viewed as a logical problem the first maze-position, Problem 1, evidently presents the least difficulty; here the hands move in the same direction on both mazes, whether forward and backward or from side to side.

Problem 2 is next in difficulty, for here one has only to remember that the two hands move always in opposite directions.

Problem 4 comes next. It is more difficult than 2 as a logical problem, for the subject has to follow two procedures with the possible danger of confusing them. In the forward and backward motions the hands are opposed, in the side-to-side motions the hands must be kept together. The maze in this position offers the complications of a mirror problem.

Problem 3 appears to be next in difficulty, involving right-angle opposition in all motions. It is like Problem 2 in having but one rule to follow, but the rule is so difficult in practice that the task is probably harder than is 4 with its two rules.

Problem 5 is like 4 in having two rules to follow, the difficult right-angle opposition of 3 made even more difficult by the mirror element presented here under even more awkward conditions than in Problem 4.

For individuals who persist in using the trial-and-error method on all problems there would be little difference in the actual difficulty of the various maze positions beyond the first. For those who proceed logically and make use of the visual cues from the upper maze, there is the greatest difference in difficulty. Most individuals, as in daily life, combine the two procedures and kinæsthetic learning is probably present to some extent in every case. If, however, we tried to avoid the learning by having unlike maze-patterns, to be used in the various positions, the comparison of the problems would be even more complicated.

3. *Error scores.* Errors in the double-maze are recorded directly by the subject. Placed beneath the lower (out-of-view) maze is a record-sheet on which the actual path is traced by the subject's pencil as he pushes it through the true path or into the blind alleys. The amount of error is

indicated by the amount of tracing and retracing in the blind alleys, and by the amount of retracing in the true path.

Subjects have been classified into four groups according to the number of errors made (see Fig. 2).

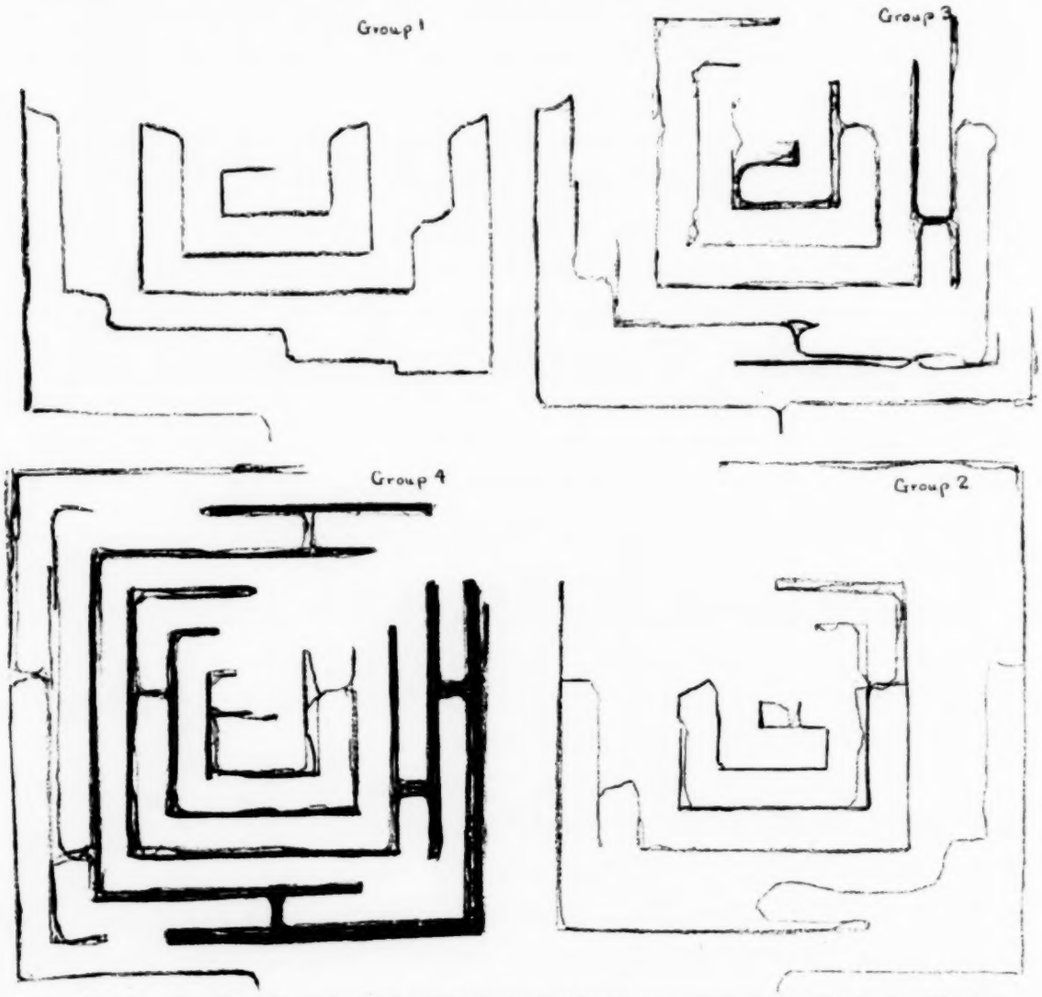

FIG. 2. Samples of the traced record typical of the four error-groups used in classification. Width of tracing in true path and in blinds indicates amount of error. Group 4 tracing (greatest amount of error) practically outlines the entire maze-pattern. Group 1 tracing (least amount of error) shows the true path.

Group 1 includes those who made practically no errors.

Group 2 is made up of those whose records on problems 1, 2 and 4 are comparatively free from error, and whose errors in 3 and 5 would equal about three times the distance of the correct path through the maze. The errors in all of the problems are, for members of Group 2, practically confined to the first part of the maze and tend to disappear near the exit.

Group 3 contains those who cover more than three times

as much ground in errors as the distance of the true path, whose records in Problems 1, 2, and 4 are not free from error, but whose errors tend to occur in one part of the maze. These subjects have not traced and retraced the entire course on a purely trial-and-error basis; they have progressed fairly adequately in all except the most difficult parts of the maze.

Group 4 is made up of those who make errors throughout and who cover all, or practically all, of the ground again and again.

When classified on this basis the 67 subjects are found to be distributed in the 4 groups as follows:

Group I, 6; Group II, 9; Group III, 19; Group IV, 33.

The errors observed by the experimenter, as well as those recorded on the tracing sheet, are not all of the same kind. They may be classified systematically as

(1*a*) the natural result of the trial-and-error method;
(1*b*) the result of failures in function of a logical method;
(2*a*) the result of failure in function of a visual method; or
(2*b*) the result of failure in function of a kinæsthetic method.

That is to say, they are (1) the result of absence or failure of a logical plan or (2) the result of failure of a predominating visual or kinæsthetic method. Any combination of the unintelligent and the intelligent, the visual and the kinæsthetic methods may occur in the course of a single problem. But in general the procedure is either unintelligent or intelligent, and may be either predominantly kinæsthetic or visual. The errors of the unintelligent method are due to chance and follow the laws of probability. They are lessened in number as visual or kinæsthetic cues enter in. Those of the intelligent method are due to lapses from a more or less definite plan. If the plan is based largely on a concept of outward pressure, the errors will be concentrated in a single region at outlet no. 5. If it is a plan involving the concept of coördination and relationship of movement, the mistakes will appear to be like those resulting from trial-and-error and may occur almost anywhere in the maze. Here again either visual or

kinæsthetic cues may reduce the number of errors. The combination of a logical with a visual and kinæsthetic method seemed to offer the surest guide to success.

4. *Relation of time score to error score.* For one of the problems (no. 2), the subjects have been distributed on the basis of both time and error scores (Table III). Those who succeeded in less than 1 min are rated I (6 cases), those who took more than 1 min but less than 2 min are rated II (9 cases), those who took more than 2 min but less than 5 min are rated III (19 cases), and those who took more than 5 min are rated IV (33 cases). The average on errors for each of the time groups indicates general agreement between the two measures. Time groups I to IV in order show error averages of 1.8, 2.6, 2.9 and 3.7.

TABLE III

RELATION OF TIME-SCORE TO ERROR-SCORE (BY GROUPS)

Time Score	Error Score				Error Average
	I	II	III	IV	
Group I	2	3	1	0	1.8
" II	1	4	2	2	2.6
" III	2	3	9	5	2.9
" IV	1	0	7	25	3.7

Those making the shortest time-record on Problem 2 tend to be those whose errors are in general fewest. The large group of 33 slow workers (5 min or more on Problem 2) includes all above the median in time. Its members make up more than 3/4 of the group of greatest error and it numbers only one individual in Error-group I (practically free from error). The group of 6 fastest workers (less than 1 min on Problem 2) includes not one individual who falls in the group making the most errors. In general, then, the slow workers are also those who make the most mistakes. (Their slowness in completion of the problem is, of course, partly the result of the tracing of wrong paths and retracing of the right one.) The quick workers are those who make the fewest. The two individuals who made a great number of errors and yet succeeded in less than 2 min moved with sufficient rapidity to compensate partly for the time lost in covering the distance added by error. Both of these were, however, among the better cases in error-group IV.

5. *Observed reaction pattern.* During each of the five parts of the experiment a record was kept in writing by the experimenter describing the subject's behavior and progress in the maze. An attempt was made to note the speed of movement, the degree of coördination of the two hands (the extent to which the two hands synchronously covered

corresponding parts of the two mazes), movement in a definite direction (outward), tendency to repeat the same errors, mood of the subject as evidenced by hand-movements, facial expression and exclamations or comments. Conclusions on the first four of these points are summarized.

(*a*) Speed of movement. There were pronounced differences in the speed of movement which are not measured by the time-score or record of the speed in reaching the exit. Of course, all else being equal, the man who moves the fastest arrives first. But all else is evidently not equal, and so it sometimes happens that the man who moves the fastest is going in the wrong direction. Some of the quickest as well as some of the slowest movers are found in the trial-and-error group. No index of correlation between speed of movement and speed in getting out could be secured; but the indications were that a positive relationship existed, *i.e.* that more rapid movement was apt to be associated with more rapid progress toward the goal.

(*b*) Coördination between the two hands. The degree of coördination observed by the experimenter proved to be the best single indicator of a logical plan. In fact, where a plan was worked out at all coördination was practically always an essential element. On the other hand, there were instances that did not involve coördination. In only a few cases were plans used where coördination was the only evident element of the plan. In these cases it was imperative for success that the coördinated movement be absolutely held to; for, if it failed, the subject had little hope of reaching the goal. Once off the track he had either to continue by trial-and-error or else to ask for a restart. Usually, coördinated movement, directed by visual impressions from the upper maze, with tactual and kinæsthetic cues from the lower maze carefully attended to, gave the best results.

The subjects have been grouped into four classes according to the degree of coördination observed by the experimenter, as follows:

I. Complete coördination; the movement of the two hands coincident in time (17 cases);

II. Fair coördination; the hands moved part of the time together, part of the time one followed the other to any given turning point (9 cases);

III. Slight coördination; some attempt made to keep the two hands in the corresponding alleys and moving in the corresponding directions (23 cases); and

IV. No coördination at all; the two hands move quite independently (18 cases).

(*c*) Movement in a definite direction. The principle of moving toward the outside is frequently used as the main guide or as a secondary aid to getting out. In some cases the pressure outward was so great that a part of the maze was momentarily pushed out of shape. Eleven subjects definitely used pressure as a means of forcing their way out. Twenty-seven others (making a total of thirty-eight) were guided by the general idea of proceeding toward the outside.

(*d*) Repetition of errors. The series was too short and the problems probably too varied for many errors to be corrected from one problem to the next. In a few cases the difficulty at Opening 5, obviously a handicap at first, was gradually overcome.

In general, those who made the best records for speed in the solution of the problems were also those whose motor activity, as response to this experimental situation, was the

more rapid; whose coördination was good; who, if not guided mainly by coördination or even when so guided, used the principle of working toward the outside of the maze; and who tended from one problem to another to reduce the number of errors proportionally.

6. *The subject's report.* The report consisted of a statement made at the close of the experiment, describing the manner of the subject's procedure in the various problems. This simple report indicated the type of cues that prevailed.

(a) Visual cues. With one probable exception, all of the subjects spoke of the visual cue presented by the upper (visible) maze as directly helpful, or else implied its usefulness by assuming visual guidance as essential to a solution of the problem series.

The top maze was 'looked at' and corresponding positions in the lower maze were 'felt for'; the relations between various positions on the top maze were 'looked at' and were then found on the lower maze; distances on the upper maze were 'noted' and matched on the lower maze; the key as well as the upper maze was referred to as a visual guide. One subject seemed to find difficulty in operating the out-of-view hand in connection with the visible maze. After attempting in the beginning of Problem 1 to move both hands at the same time, she altered her procedure so as to work the upper pencil through to the exit while holding the lower one firmly at its starting point, and then with the upper pencil 'out of the way' she devoted herself to 'feeling through' the invisible maze. As it appeared to the experimenter that she paid no attention to the key or upper maze while doing this, it seemed probable that here was a case where the visual guidance made possible by the upper maze was not accepted. It may be said that this subject had trouble even with the first problem, requiring more than a minute-and-a-half to solve it, and that she made a great many errors even in this simple situation. The subject who said, "I took a look at the upper maze and saw the way to get out" expressed what was obviously the usual procedure. For some, however, the indirect guidance was insufficient. They wanted to 'see the lower maze.' The out-of-view hand was 'in the dark'; the lower maze especially when rotated or inverted no longer 'looked like' the upper maze. One subject pulled out a pocket mirror when Problem 4 was presented, and, before the experimenter had time to protest, viewed the upper maze in it, saying "Experience is better than theory!" The same subject had remarked during an earlier problem "I can't do *anything* without seeing," and at another time, "I think if ever I go blind I'll commit suicide."

With one possible exception, then, all of the subjects (66 cases) made some use of the visible maze and 29 cases used also the key as a guide in working out the lower path. Visual guidance in the nature of a visual image of the lower maze was also reported.

"I tried to see in my head how the other maze looked;" "You see in your head the relative positions and then think the directions;" "I had one eye on the upper and one on the lower maze;" "I pictured how it should go;" "I tilted it over in my mind;" "I made a map of the lower maze in my mind and followed that." These were among the phrases descriptive of the visual imagery reported by eighteen subjects as their main imaginal cue, and by nineteen more as a partial cue. The nineteen reported kinæsthetic (or tactual) imagery as well.

(b) Kinæsthetic cues. From their reports, it seems probable that all of the subjects used kinæsthetic or tactual guidance given by the upper maze.

Subjects stated that they 'felt' the distances on the upper maze and compared the lower paths with these. They 'felt' the turns, the edges and the exits of the two mazes, and compared them. Thirty subjects reported 'feeling' as their main cue in directing movement. Nineteen others depended on a combination of feeling and seeing the out-of-view maze. Particularly in Problems 3 and 5 kinæsthetic cues played a large part. "I felt around until I found where I was;" "If lost I tried to find a familiar shape;" "I felt for corners and holes;" "I *felt* and then looked for *that*;" "I tried to get to know the *feeling* of the center, and then worked from that;" "I did it all just by feeling, I wasn't clever enough to do it any other way;" "I looked at the upper maze, but depended mainly on feeling the other one." Subjects seemed to realize that a cue had value in the given situation only as it was of assistance in reaching the goal. They tended to discard those that hindered instead of helping. "I tried to visualize the lower maze; but that was too hard, so I gave that up and just felt it." "I tried to think of the directions, but that didn't work, so I just pushed toward the outside," etc. 'Feeling' the lower maze seems to have been generally regarded as easier than 'seeing' it.

(c) Other cues. Beside visual and kinæsthetic guidance subjects reported other cues or logical plans of procedure as follows: (*A*) Concrete, definite plans in terms of position (32 cases). These may be subdivided into (1) a plan of movement toward the supposed position of the exit (16 cases); (2) a plan of movement away from the supposed position of the center (4 cases); (3) a plan of pressure toward the outside (12 cases). (*B*) Abstract plans (81 cases) [5] may be further subdivided into (1) coördination; moving both hands at the same time in the corresponding alleys or through the corresponding openings in the two mazes (22 cases); (2) verbal directions; saying "Upper hand forward, lower hand back," or the like (10 cases); (3) attending to the relation of the positions of the lines to one another; 'at right angles,' 'opposite,' etc. (49 cases).

[5] Many individuals reported more than one abstract plan, hence the total number of plans exceeds the number of individuals.

Trial-and-error was frequently mentioned: "I didn't know which way to go, but just kept going;" "I had no idea how to proceed;" "I was lost, just went on to see where I would come out." From the reports, checked by the examiner's observations, it appeared that practically the entire procedure was trial-and-error in at least 15 cases; that about half of the procedure was trial-and-error in 24 cases; that 17 cases were fairly free from trial-and-error (but with lapses), while 11 cases were almost entirely free from any trial-and-error.

The difficulty at Opening 5 (*i.e.* the one inward opening, all other openings leading outward toward the exit) was recognized in the first experiment and error avoided at that point thereafter in 1 case. In 17 cases the existence of one inward passage was noted and effort was made to reduce errors at that point. In 15 cases there was some realization of the situation; but passage through the opening continued to be effected only with great difficulty. In 34 cases the subjects were apparently not sufficiently aware of the nature of the difficulty to attempt regularly a logical scheme of escape.

7. *Sex differences.* The men students as a group attacked the problems more intelligently than did the women. Among the men there were none, but among the women six who wanted to give up as soon as they had begun and who apparently did not do their best. The mean time-score on Problem 1 was for the 39 men students, 84 seconds; for the 28 women students, 112 seconds. Comparisons of time-scores on the 5 problems give the results tabulated in Table IV.

TABLE IV

COMPARISON OF TIME-SCORES OF MEN AND WOMEN ON 5 MOTOR-SPACE PROBLEMS

	I	II	III	IV	V
No. of subjects...	M.39, W.28	M.39, W.28	M.37, W.27	M.34, W.25	M.33, W.22
Per cent. women as slow as, or slower than, slowest man .	7	15	15	16	27
Per cent. women as slow as, or slower than, median man.	57	75	56	80	45
Per cent. women as slow as, or slower than, fastest man..	100	100	100	100	100
Per cent. men as slow as, or slower than, slowest woman....	0	13	16	0	18
Per cent. men as slow as, or slower than, median woman....	33	26	46	24	54
Per cent. men as slow as, or slower than, fastest woman.....	95	92	89	97	97

A glance at the table shows that the women as a group

required more time than the men to solve each of the problems. No woman was as fast as the fastest man in any problem. The per cent. of men faster than the fastest women ranges from 11 in Problem 3 to 3 in Problems 4 and 5. In two problems (1 and 4) no man was as slow as the slowest woman. In all of the others there were a number of men in the slowest group. The women, as a group, are, when compared with the men, slowest on the problems which, if our analysis was correct, are logically in second and third place in difficulty. They are quickest of all on the problem which is logically the hardest (5). The probable explanation for the better showing on 5 is the same for all slow workers; namely, that having spent so much more time on the other four problems than the faster workers they have 'learned' the maze better at this point.

8. *Summary of results.* Results on this series of five motor-space problems showed certain individual differences (1) in success whether measured by speed or by freedom from error, and (2) in reaction pattern as observed by the experimenter and as reported by the subjects. Time- and error-scores showed an expected tendency to fairly regular negative agreement. There was evidence of sex differences in the time-scores.

A proposed logical order of difficulty was found to be the order indicated by the time-scores of the fastest workers. In the case of the slower workers a learning factor appeared to have confused the issue and to have made the time-scores measures of learning as well as of the difficulty of the problems. As a rule the faster the worker the freer he was from error. Different types of errors occurred according to the method of procedure and the imagery used.

The observed reaction pattern gave evidence of certain typical procedures that proved successful in the problems as a whole and were followed to some extent by many of the subjects. These procedures were (1) a fairly rapid rate of movement, (2) coördination between the two hands, (3) movement in the general direction of the outside of the maze and (4) in some cases an effort to avoid the repetition of certain errors.

The reports indicated that visual cues were used in all but one case, that solution also frequently proceeded by kinæsthetic or tactual guidance, that these were often combined with other cues, some concrete (such as pressure toward the outside), others abstract (such as verbal formulas or the relation of directions). The procedure of the women appeared in general less adequate than that of the men.

D. Conclusion

Five motor-space problems presented in sequence on a Miles double-maze were found, in spite of the fact that they presented the same pattern, to show differences in relative difficulty according to the position in which the out-of-view maze was placed. The problem was not one in learning; but it appeared that slow workers, those who had difficulty in solving the problems, did begin to learn the maze pattern. In their cases the relative difficulty of the problems was altered so that for them the harder problems, if they occurred later in the series, were proportionally easier. This suggests that, after learning, the double-maze would show results similar to Perrin's with rotated maze patterns, *i.e.* that when the maze-pattern was once learned it would not matter, so far as speed of tracing was concerned, in what position it was placed. The problems for the double maze were not 'trial-and-error' or 'trial-and-trial,' as would be the case with the ordinary blindfold maze; for here indirect visual guidance was provided by the upper maze. The types of cue and imagery used for guidance were found to show considerable individual difference. But a combination predominately visual and secondarily kinæsthetic, with certain other slighter cues and procedures, proved effective for most subjects in solving the series of problems taken as a whole.

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A STUDY OF POETIC TALENT

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The plan of this study[1] was to give a series of tests to two groups of subjects, the one possessing and the other decidedly lacking in poetic talent. It was hoped, first, that the results would throw light upon the nature of poetic talent; and, secondly, that some of the tests used might be found to be sufficiently distinguishing for use in the teaching of literature.

Just what the factors are which make up poetic talent it is at present difficult to say. A survey of the literature discloses the fact that many writers refuse to attempt a definition of poetry and disagree in their analysis of the essential elements either in poetry or in poetic talent. Imagination, imagery, emotion, rhythmical form and trope have all been mentioned as essential features. It seemed wise, therefore, in this study to attempt no definition at the outset but rather to design a series of tests in the hope that some of them would differentiate between the two groups of subjects; the results might, then, whether positive or negative, throw light upon the nature of poetic talent, since we know that to be the outstanding feature in which the two groups differ; and, if positive, might be so developed as to enable young writers to compare their records with others in the same field.

The subjects in this experiment may be divided into two main classes; *A* is composed of twenty-eight individuals who have poetic talent and *B* of twenty-eight who, according to their own statements, do not try to write poetry and have little or no interest in reading it. Each class may be subdivided into three groups representing progressive degrees of maturity and attainment: Group I, high school students; Group II, college undergraduates and two graduate students; Group III, more mature persons with some definitely developed interest.

The criterion of poetic talent necessarily varied with the three groups. Group I*A*

[1] The study was made under the direction of Dr. L. L. Thurstone.

consists of eleven pupils who were distinguished by their high school teachers of English as having poetic talent. Both of these teachers hold courses in poetic appreciation; one of them has published poems and served as a subject in Group III*A*. Only those students were used who evinced, upon questioning, some interest in writing in addition to assigned class exercises.

Membership in the Poetry Club of the University of Chicago, which has definite standards of productivity as a basis of selection, was accepted for admission to Group II*A*. Several of the subjects were not members of the Poetry Club but had published in *Poetry*, *The Nation*, or in volumes of verse. The members of Group III*A* have either published in such magazines as *Poetry* and *The Atlantic Monthly* or have published a volume of verse.

The members of Class *B* were chosen to match approximately the members of Class *A* in intelligence, age and education. Group I*B* consists of high school pupils who are described by their teachers of English as having good general intelligence but very little interest in poetry; they themselves when questioned report little interest in reading poetry and no attempt to write in verse. In Groups II*B* and III*B* the subject's own report of his lack of interest and ability in poetry was accepted as a basis of selection, some check being made as to his general intelligence by inquiries concerning his success in other directions. In some cases the subject was conspicuously successful in one of the sciences, and in every case there is indication of general intelligence and education comparable to that of the poets.

Description of the Materials Used

A series of ten tests, requiring from two-and-a-half to four hours, was given to each subject. At the beginning of the period it was explained to the subject that these were not intelligence tests, and that he might ask questions whenever he chose.

1. *Rhymes.* The task of finding rhymes was taken from Tolman's study of students with literary and scientific interests (23), in which he found that the students of literature did better than the students of science.

The following directions were given to the subject: "I am going to read a list of words to you. After each word is read you will be given one minute in which to think of as many words as you can which rhyme with the word I have given." The subject wrote the words as he thought of them. The words used were: precede, ample, delay, pencil, delight, weather, destroy, mixture, affair, wagon, assess, nourish, arrange, butter, defend, churlish, review, hardy, commit and kettle.

2. *Controlled Association.* In Part *A* the subject was told: "I shall read a list of nouns to you. After each noun is given you are to write as many adjectives as you can which might apply to that noun. You will be given one minute for each noun. For example, if I say 'sky' you might give such words as gray, stormy, lovely, foreboding, etc. Write all the adjectives you can think of till I say 'Stop.'" The nouns given were: butterfly, dream, blossom, eagle and mountain.

In Part *B* the subject was given five adjectives (smooth, blue, swift, dark and deep). For each he was to list as many nouns as he could which that adjective might modify. He was then given five nouns (ocean, noon, priest, music and spider) for which he was to list verbs.

3. *Imagery.* Although the limitations of a questionary on imagery were recognized, still, since the amount and vividness of imagery are an alleged part of the enjoyment and production of poetry, it seemed worth while to give a test of this type. After an explanation of the term 'imagery,' the experimenter said; "Now, I am going to give you some things to imagine and I want you to try to see or hear or smell or feel whatever I tell you to. In each case tell me how vivid your imagery is, using the number 3 to indicate that it is almost as clear as the actual sense-experience would be; 2 that you have a fairly clear image; 1 that you have a barely perceptible image; and 0 that you cannot get the image called for. As it is sometimes difficult to be sure of one's imagery, I will check from time to time by asking questions." An indication of the questions asked as checks is given in parentheses in the list of stimuli used. These questions were asked to make the subject more self-critical; in every case the subject's own estimate of his imagery was recorded.

A. Visual 1. A bird. Can you see a bird? (Where is it? What color is it?)

2. A moonlight scene.

3. The face of a good friend. (Smiling?)

B. Auditory 1. The whistle of a train. Can you hear it? (Is it high or low in pitch?)

2. The splash of water on rocks. (Was it a loud splash?)

3. The howling of a dog.

C. Olfactory 1. The odor of lilacs. Can you smell lilacs now?

2. Hot coffee.

3. Burning leaves.

D. Cutaneous 1. Ice on your forehead. Can you feel the coolness?

2. Something warm in your mouth. (What is it?)

3. A rose petal brushed across your cheek.

E. Organic and kinæsthetic 1. Can you get the feeling of suddenly coming down in an elevator?

2. Of running very fast?

3. Of flying? Not in an aeroplane, but you, yourself, flying.

4. *Rhythm.* Seashore's test of rhythm (one of his series of tests of musical talent) was given.

5. *Affective Reaction.* This test was suggested by the work done by Washburn, Hatt and Holt on affective sensitiveness in poets and scientists (25). They used fifty nonsense syllables and fifty color combinations for each of which the subject expressed his judgment of pleasantness or unpleasantness by using any of the numbers from 1 to 7, 1 meaning extreme unpleasantness, 7 extreme pleasantness, and 4 indifference. In the present experiment three kinds of material were used; a list of thirty words (such as arrogant, bubbles, supercilious, slimy, etc.); fifteen things to be perceived (such as a black metal box, a selection from *Carmen* on the victrola, colored papers, scarves, etc.), and fifteen experiences to be imagined (a violent storm, rotten eggs, the feel of the hand on soft hair, etc.).

6. *Completion.* The directions were: "In each of the following quotations from poetry there is a blank into which one or more words should be fitted. Write the best word or phrase you can think of to put into this blank."

a. Lovely and illusory,
Dreams do well enough for me:
What to you, then, if I choose
To walk the world in ..... shoes?

b. The tones like ..... into the stillness curl,
The slippered hours their placid business ply.
c. The mail has come from home,
From home that still remembers, to Japan,
My tiny maid, as faultless as .....
Bows in the doorway.
d. Then hard behind, a stately galleon
Sails onward with its piled and ..... towers,
Stiff sculptured like a heap of marble flowers.
e. Bring, in this timeless grave to throw,
No cypress ..... on the snow.

The words and phrases used by the authors themselves were; (*a*) wingéd; (*b*) smoke; (*c*) her fan; (*d*) carven; (*e*) sombre.

7. *Rorschach Test.* This is a form of the ink-blot test in which the designs are quite complicated. The first five and the last of the Rorschach cards were used. The subject was asked to look at each card and to tell what he saw. A complete record was kept of the subject's comments.

8. *Similes.* In Part *A*, the subject was instructed: "The following lines are taken from poetry. Each quotation is an incomplete simile. You are to suggest as many ways as you can to complete it. You will be given two minutes for each. Do not attempt to get good poetic form,—rhyme, rhythm, etc. Simply list ideas which might be worked into the poem as similes. For example:

"The yellow moonlight dead
Lies silent as — — —
the grave, a word unsaid, etc."

The quotations which were given were

a. The other was a softer voice, as soft as — — —
b. With the stars aswirl behind them
Like — — —
c. When I play on my fiddle in Dooney
Folks dance like — — — —
d. I like a road that leads away to prospects white and fair,
A road that is an ordered road, like — — —

In Form *B* the directions were; "Now I am going to read a list of things to you and this time you are to suggest the symbols which may stand for them. For example, sadness may be symbolized by a rainy day. Find all the symbols or metaphors you can for the following: life; failure; treachery; marriage for money; courage." Two minutes was allowed for each.

9. *Memory.* The subject was informed that the experimenter would read a short passage from poetry and after each reading the subject was to repeat as much of it as possible. If the subject had not given a correct repetition after five readings the experimenter went on to the next selection. Five passages, each consisting of three or four lines of poetry, were read.

10. *Abbott and Trabue Exercises in Judging Poetry.* Series *X* of these exercises was used. The subject was asked to read four versions of the same poem, in which three of the versions are inferior to the original in emotion, imagery or rhythm, and to choose the best and the worst of the four versions in each set. There were thirteen sets.

Results

Methods of scoring. The score in the first test is the total number of rhymes given to the twenty stimulus-words. Two scores are obtained for the Controlled association test: the total number of words given to the fifteen stimulus-words and the total number of figurative words given to the fifteen stimulus-words. A response is considered figurative when a quality or an activity is attributed to a noun which could not literally have that quality or activity. Examples are: golden dream, dark love, ocean dances, music quivers, swift skates, blue evening. The score in imagery is the number of images experienced according to the report of the subject. In the section on rhythm (4) the score is the per cent. of correct judgments. Percentile ranks were found from the Seashore tables.

A total score in Affective reaction (5) was obtained in each test by giving an arbitrary value to each judgment: a judgment of 4 was called 0; a judgment of 3 or 5 was called 1; a judgment of 2 or 6 was called 4; and a judgment of 1 or 7 was called 9. So it is seen that when a subject expressed himself as neutral he was given no score at all for affective reaction; when he indicated extreme liking or disliking he was given a high score. The number of judgments of each type (from 1 to 7) was counted and then multiplied by the corresponding assigned value (from 0 to 9); these numbers added give the score of affective reaction in each form of the test.

In the tables and in the discussion of specific tests the results of the Affective reaction test are omitted. No differentiation was obtained and, as the material is of a type difficult to present in brief form, it seems wise not to present it at all. The results of Washburn and her students led us to think that something might be done with a test of this sort and it may be that with modification of some kind it will still prove useful. It is for this reason that we have included a description of the test, the method of scoring and the statement that no differentiation was found either by a comparison of average scores or a determination of critical scores.

The scoring in the Completion test is necessarily subjective. Five members of the Department of English, all of whom teach courses in Poetry, read a list of all the words and phrases suggested for each quotation, including the original, and selected the five which seemed best, arranging them in order of merit. The judges worked independently and without knowing whether any particular suggestion was made by a poet or a non-poet. The five words or phrases given first place for the five different quotations by any one judge were given five points each. The words chosen as second in merit were given four points each, etc., down to the fifth choice which was given one point. Then the five sets of judgments were combined so that a word which was chosen by several judges would have the total score obtained. Every word selected by one or more of the five judges was thus given a numerical value and words not selected by the judges were given zero. The score of any one subject was found by adding the numerical values of the five words he had suggested.

In the Rorschach Test (7) the score is the total number of items suggested for all the cards presented. In addition to the number of responses Rorschach mentions as significant the character of what is seen, the method of perception, and the size of the part interpreted. Following such suggestions, we made an attempt to score on some such basis; but as no differentiation occurred these methods were abandoned. (For further differences see below.)

In the test on Similes (8) the score in Form *A* consists of the total number of similes and in Form *B* of the total number of metaphors given. The scores of the two forms are added to give a single total score for the test. The difficulty in scoring lay in deciding which of the comparisons made could be accepted as real similes and metaphors, for it was found that a large number of suggestions were made, especially by the control-subjects, which were not figures of speech. For the quotation, "When I play on my fiddle in Dooney, Folks dance like ———," such a suggestion as "leaves in the autumn" is accepted as a simile for there is

the common element of rapid, unconstrained movement with all its associations and beyond that no similarity at all. 'Olden times' on the other hand is rejected. The suggestion here is that folks dance as they danced in olden times, but this is descriptive. Suggestions were usually rejected either because they were of a descriptive nature or because there did not seem to the judges to be a real element of similarity between the two items compared.

The test on Memory (9) was scored by counting the total trials given to each subject. When a subject failed to learn a given selection the number of trials was counted as six.

The method of scoring in the Abbott and Trabue Test

TABLE I

AVERAGE SCORES OF POETS AND NON-POETS

Materials	Class	Mean	Sigma	P.E.$_M$	Diff. bet. means	P.E.$_D$	$\frac{D}{\text{P.E.}_D}$
Rhymes (Total no.)	*A*	101.18	27.79	3.52			
					44.25	4.33	10.21
	B	56.93	22.93	2.90			
C. Ass'n (No. words)	*A*	129.72	36.25	4.59			
					27.73	5.72	4.85
	B	101.99	26.99	3.42			
C. Ass'n (No. figurative words)	*A*	13.64	8.27	1.05			
					9.95	1.11	8.97
	B	3.69	2.96	.37			
Imagery (No. images)	*A*	13.41	1.76	.22			
					4.06	.25	16.24
	B	9.35	.96	.12			
Rhythm (Per cent. correct judgm'ts)	*A*	80.33	6.74	.85			
					2.32	1.31	1.69
	B	78.11	7.9	1.00			
Completion	*A*	12.99	10.65	1.35			
					7.11	1.52	4.68
	B	5.88	5.51	.7			
Rorschach (No. items)	*A*	50.30	19.36	2.45			
					23.36	3.04	7.69
	B	26.94	14.18	1.79			
Similes	*A*	26.76	13.23	1.67			
					16.60	1.85	8.93
	B	10.16	6.34	.80			
Memory	Group III*A*	15.33	5.18	1.16			
					8.00	1.75	4.56
	Group III*B*	23.33	5.89	1.31			
Abbott and Trabue	*A*	9.76	2.50	.32			
					4.83	.42	11.50
	B	4.93	2.20	.28			

TABLE II

UPPER AND LOWER CRITICAL SCORES (p = poets, n-p = non-poets)

Rhymes	*C. Ass'n* (No. Words)	*C. Ass'n* (No. Figurative Words)	*Imagery* (No. Images)	*Rhythm* Percentile Ranks	*Completion B*	*Rorschach*	*Similes*	*Memory*	*Abbott and Trabue*
Above 110	Above 162	Above 10			Above 20	Above 60	Above 22	Below 12 trials	Above 12
11 p	7 p	15 p			5 p	9 p	14 p	3 p	4 p
0 n-p	0 n-p	0 n-p			0 n-p	0 n-p	0 n-p	0 n-p	0 n-p
Above 100	Above 130	Above 5	Above 13	Above 75	Above 15	Above 40	Above 20	Below 15 trials	Above 9
15 p	12 p	24 p	17 p	14 p	8 p	19 p	16 p	4 p	15 p
1 n-p	4 n-p	7 n-p	5 n-p	9 n-p	1 n-p	5 n-p	1 n-p	1 n-p	1 n-p
Below 60	Below 90	Below 6		Below 25	Below 5	Below 20	Below 10	Above 25 trials	Below 6
1 p	2 p	4 p		2 p	8 p	1 p	1 p	1 p	3 p
14 n-p	11 n-p	21 n-p		4 n-p	16 n-p	13 n-p	16 n-p	6 n-p	23 n-p
Below 45	Below 68		Below 11			Below 12	Below 8	Above 27 trials	Below 5
0 p	0 p		0 p			0 p	0 p	0 p	0 p
9 n-p	3 n-p		25 n-p			8 n-p	16 n-p	5 n-p	14 n-p

is slightly different from that of its authors. They use as the score the number of correct judgments. In this experiment the correct judgments were counted but there was also a penalty of one point for each time that the subject called the best selection the worst.

Explanation of the tables. Table I enables the reader to compare the mean score of the poets with the mean score of the non-poets in each test. In Table II the reader can find the upper and lower critical scores in each test. In the second horizontal line are given the scores above which there are some poets but no non-poets; and in the third horizontal line are given the scores above which there are a few non-poets but many more poets. The lower critical scores below which there are a few poets and many non-poets are given in the fourth line; and in the last line are the scores below which there are no poets and some non-poets.

TABLE III

TESTS IN WHICH THE INDIVIDUAL POETS IN GROUP III*A* RECEIVED HIGH SCORES

Subj.	No. of Tests	Names of Tests
A	8	Rhymes, Imagery, Rhythm, Controlled Association (number), Completion, Similes, Memory, Abbott and Trabue
B	7	Rhymes, Controlled Association (number), Controlled Association (figurative), Rorschach, Similes, Memory, Abbott and Trabue
C	7	Rhymes, Controlled Association (number), Controlled Association (figurative), Rorschach, Similes, Memory, Abbott and Trabue
D	6	Rhymes, Controlled Association (number), Controlled Association (figurative), Imagery, Rorschach, Similes
E	5	Rhymes, Controlled Association (figurative), Rhythm, Completion, Similes
F	5	Controlled Association (number), Controlled Association (figurative), Similes, Imagery, Abbott and Trabue
G	5	Rhymes, Controlled Association (figurative), Imagery, Similes, Abbott and Trabue
H	4	Rhymes, Controlled Association (number), Imagery, Rhythm
I	4	Rhymes, Imagery, Rhythm, Abbott and Trabue

In Imagery a high score means 13, 14, or 15 images of the 15 suggested; in Rhythm it means a percentile rank above 75; in the other tests it means a score higher than that received by any non-poet.

TABLE IV

TESTS IN WHICH INDIVIDUALS IN GROUP II*A* MADE A HIGH SCORE

Subj.	No. of Tests	
A	6	Controlled Association (number), Rhythm, Completion, Similes, Memory, Abbott and Trabue
B	6	Rhymes, Controlled Association (figurative), Rhythm, Completion, Rorschach, Similes
C	5	Controlled Association (figurative), Rhythm, Completion, Similes, Abbott and Trabue
D	3	Controlled Association (figurative), Imagery, Rorschach
E	3	Imagery, Rhythm, Rorschach
F	3	Rhymes, Controlled Association (figurative), Imagery
G	2	Controlled Association (figurative), Memory
H	1	Similes

(See note below Table III)

TABLE V

TESTS IN WHICH SUBJECTS IN GROUP I*A* MADE A HIGH SCORE

Subj.	Total No. Tests	
A	6	Rhymes, Controlled Association (figurative), Imagery, Rhythm, Similes, Abbott and Trabue
B	3	Imagery, Rorschach, Abbott and Trabue
C	3	Controlled Association (number), Controlled Association (figurative), Abbott and Trabue
D	3	Controlled Association (figurative), Imagery, Abbott and Trabue
E	3	Imagery, Rhythm, Rorschach
F	3	Imagery, Rhythm, Rorschach
G	3	Controlled Association (figurative), Rhythm, Similes
H	2	Imagery, Rhythm
I	2	Imagery, Rhythm
J	2	Rhythm, Similes
K	0	

(See note below Table III)

Tables III, IV and V give the records of individual poets. Table III shows in which tests each individual poet of Group III*A* (the group most advanced in poetic production) made high scores. A 'high score' is a score higher than that made by any non-poet, except in the tests on imagery and rhythm, where no upper critical scores were found. In the test of Imagery 'high score' means the experience of 13, 14, or 15 of the 15 images suggested; in Rhythm it means a percentile rank above 75.

Discussion of the results. Of the ten tests, seven differentiate between the two classes of subjects in two ways; first, in the higher average scores of the poets, and, secondly, in the existence of upper critical scores above which there are some poets and few or no non-poets and lower critical scores below which there are some non-poets and few or no poets.

1. *Rhymes.* The average number of rhymes given by the poets is 101.18 and by the non-poets is 56.93. Eleven poets give more rhymes than any non-poet and nine non-poets give fewer rhymes than any poet. The members of Group III*A* give more rhymes than those of Group I*A* or II*A*. It is also interesting to note that among the poetic subjects there were six who reported that they wrote at least as much free as regular verse and these six obtain the six lowest scores among the poets.

It is probable that the ability to find rhymes is to a large extent a matter of intelligence and practice. Even so, the relation of this ability to the production of poetry is important. In the first place, in the finished product rhymes add much to the pleasure of the reader; and if a poet is going to write that sort of verse a facility in the mechanical part is certainly an advantage. In the second place, rhymes are often a stimulus to further thought.

2. *Controlled Association.* The average number of words given by the poets is 129.72 and by the non-poets 101.99. These figures represent the results of all groups and all stimulus-words. If we compare the score of the poets with that of the non-poets in each of the three groups for the 15 stimulus-words separately, we find that out of 45 possible comparisons, the poets give more words 42 times.

More interesting than the number of words is the type of word given. The average number of figurative words given by the poets is 13.64 and by the non-poets 3.69. Fifteen poets and no non-poets give more than ten such words whereas only four poets and twenty-one non-poets give less than six. The significant element in these results is not that the poets *can* use more figurative expressions when they

are trying to do so, but that they spontaneously use more in a situation where it is possible but neither required nor suggested. These expressions are a subtle and indirect form of comparison; by attributing to one object a quality which belongs to another one suggests a likeness between the two. As will be seen later in this paper the poets exceed the non-poets in the ability to give similes and metaphors; but there the task is directly set. Here we have a case where the figures come uninvited.

3. *Imagery.* The average number of images experienced by the poets is 13.41, by the non-poets 9.35. There is no upper critical score; for, although all the poets report at least 11 of the possible 15 images, some of the non-poets report the experience of all of them. The variation among the non-poets is much greater than among the poets.

4. *Rhythm.* The poets and non-poets are not here differentiated either in the average scores or in the existence of critical scores. Only fourteen of the poets (half of the total number) have percentile ranks above 75.

6. *Completion Test.* The average score of the poets is 12.99, of the non-poets 5.88. Five poets and no non-poets score above 20. The difficulty of getting an objective standard of judgment of the results is a drawback in this test; it seems justified, however, since the results indicate not only that the poets can write better than the control-subjects (as we knew before beginning the exercises), but that their productive ability is also better when the situation is defined within narrow limits at the start.

7. *Rorschach Test.* The poets give an average of 50.30 items, the non-poets 26.94. Nine poets and no non-poets give more than 60 items. Eight non-poets and no poets give less than 12 items. When the numerical scores of the poets are low they compensate for their meagre number of perceptions by a richness of interpretation and description; whereas the non-poets whose scores are very low give exceedingly little supplementary information about the items mentioned. But the non-poets who give a relatively high number of items elaborate as much as the poets.

Symbolism of some sort is mentioned by nine of the poets and their emotional reaction to the card is stated by five of them. None of the control-subjects give either of these types of responses.

8. *Similes.* The average number of similes and metaphors given by the poets is 26.76, by the non-poets 10.16. Fourteen poets and no non-poets give more than 22 while sixteen non-poets and no poets give less than 8.

The striking difference between the poets and the non-poets on figures of speech, both here and in Controlled association, is significant. Aristotle says in the *Poetics;* "but the greatest thing by far is to have a genius for metaphor. This alone cannot be had from another; it is the mark of a gifted nature—for to make good metaphors implies an eye for resemblances." And Kate Gordon, writing more than 2000 years later, remarks that "the essential creative moment in thinking is that in which the mind sees likenesses, when it perceives a similarity or partial identity which did not appear before. The genius is he who 'spots' the elusive similarity or the hidden identity between different things which escapes other minds. . . . The writer who wishes to enrich and illumine his subject proceeds to liken it to something. Thus he produces figures of speech, and perhaps new combinations of old material."

This ability to find similarities is not, of course, exclusively characteristic of poetic talent. It is, as Miss Gordon points out, the mark of genius in any field. Even within language we find that the figurative element characterizes slang as well as poetry! "A hot time" and "You'll have to step on it" are no less figurative though far less poetic than "Daughters of Time, the hypocritic Days." What is the element which turns some figures of speech into slang, some into humor, and still others into poetry? This question of figurative language is provocative of further research.

9. *Memory.* Since it was necessary to use the memorial material in slightly different form for the three groups, the results must be treated separately. Therefore only Group III is presented in the table (I). The average number of trials

necessary for the poets was 15.33 and for the non-poets 23.33. Three poets scored higher than any non-poet. Although an attempt was made to use passages which were not widely known, it is possible that the poets were slightly familiar with the material and thus had an advantage over the non-poets. Unfortunately there was not time to test the ability in memorizing non-poetic material.

10. *Abbott and Trabue Exercises in Judging Poetry.* The average score of the poets is 9.76 and of the non-poets is 4.93. Only four poets score higher than any non-poet but fifteen poets and only one non-poet score above 9. This test is really one of poetic appreciation rather than one of talent and it may be that lovers of poetry who have no productive ability would do even better than the poets.

Indeed, we must remember in considering any of our materials that an attempt was made to avoid subjects who had poetic appreciation but no productive talent. Whether the differences which have been found between the poets and non-poets would exist also between a group of poets and a group of lovers of poetry we cannot tell.

Neither do we know to what extent the tests indicate innate abilities or the effects of practice. The differences between the poets and non-poets are in general more marked in Group III than in Groups I and II. This may be due to the greater practice of the more mature group; on the other hand, this group is made up of individuals who, as we may assume, have more talent than the members of Groups I and II, since they have remained in the field a longer time and have met a more rigorous test of their ability. Whether it is a matter of practice or of native talent, however, these results do show existing differences between the poets and others.

Summary and Conclusion

In the present study we have an indication of several characteristics of poetic talent. The poets show an ability to rhyme with more facility than the controls and they exhibit a larger vocabulary. This vocabulary might not be larger if a reading knowledge were being tested; but the

poetic subjects are able to produce more words than others in a given situation.[2] From the subjects' reports it appears that the poets experience a relatively large amount of imagery. Their 'sense of rhythm' is not so good as one would expect it to be; but this may be due to the character of the test. The poets are able to see more things in the Rorschach ink-blots than the non-poets, which may be considered an indication of at least a certain type of imagination. Their memory for poetic material is better than that of their fellows. But the most striking and significant fact of all lies in the difference between the two groups with respect to figures of speech. This difference comes out with the use of similes and also in controlled association. The ability to see a likeness in two otherwise dissimilar things and likewise the tendency to use phrases involving such an apprehension are especially characteristic of the poetically talented group. It is in this direction that future studies should be most fruitful.

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[2] One might point out that the number of words is not important. We are reminded of the incident of Sentimental Tommy who lost the prize in Composition because he spent the whole period waiting for exactly the right word to come, and, as it failed to appear, wrote nothing. But the chances of exactly the right word coming and of the poets getting happy phrases for their verse are greater if a large number is available, unless poetry is looked upon as purely inspirational and inexplicable.

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A COMPARISON OF THE 'WHOLE,' 'PART' AND 'COMBINATION' METHODS OF LEARNING PIANO MUSIC

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Musicians are not generally interested in the psychology of learning. They are often content to let habits and 'intuition' hold sway without considering the possibility that principles formulated in other fields may be valuable in learning music. Others, more thoughtful, have concluded, by way of analogy or common sense or by having achieved some degree of success through its use, that one way is better than others. But proof is still lacking.[2]

In our experiments the three methods used were whole, part and combination. In the first the score was played from beginning to end without stopping to correct or to repeat measures where errors occurred. In the part-method the score was divided into units and each unit was practised an equal number of times. In the combination-method the score was played from beginning to end but all measures where errors occurred were repeated an equal number of times.

The scores were chosen in groups of threes, each group forming a unit.[3] Each unit involved (1) the same number

[1] The author is heavily indebted to Professor L. L. Thurstone and to Dr. T. G. Thurstone for supervision and constructive criticism and to Dr. A. W. Kornhauser for his interest and encouragement in the early stages of the study.

[2] "In an inventory of methods actually used by one hundred prominent musicians, fourteen reported that they employed the whole method exclusively, another fourteen combined the whole and the piecemeal procedure, while the remaining seventy-two learned mainly bit-by-bit. These data throw little light on the merits of the methods inasmuch as highly competent performers in every field often employ uneconomical methods. Crucial investigations in the case of such functions are lacking. Theoretically, the whole method would seem to possess the same merits here as in the case of memorizing poetry or prose," A. I. Gates, *Psychology for students of education*, 1923, 293.

[3] The scores used were suggested by Miss Mary Quin, instructor of piano at the Institute of Musical Art, New York City, and Mr. Harris Vail, instructor of Church Music, University of Chicago.

of measures in each of the three scores forming a unit, (2) the same number of beats in the measure, and (3) the same general degree of difficulty.

The units were played by students at sight, and the time required to play each score recorded by a stop watch. The essential demand made of the students was accurate playing and the correction of mistakes. The various records of time were added and the relationship of the summations within the same unit was regarded as an approximate relationship of difficulty.

Preliminary Trials

The learning of the first three units, *i.e.*, three groups each containing three scores, constituted the preliminary study. Here progress was measured chiefly in terms of the elimination of errors. Mistakes in notes, pausing, values and fingering were regarded as errors. Since phrasing and expression were factors in musical interpretation, they were disregarded. Where two errors were the result of one mistake, *e.g.*, the playing of a wrong note with a finger not indicated in the score, the two errors were regarded as one. But if a wrong finger was used to begin a scale-passage with the result that the whole passage was misfingered, each individual error was counted. Again, if double notes were tied and the error consisted in disregarding the tie, only one error was recorded.

Tempo. The same tempo was maintained by the metronome for each of the three pieces played at one sitting. A very slow tempo was set for the first sitting in order that the number of mistakes might be sufficiently small to permit their being counted. Gradually the tempo was increased until the required metronome value was reached where it remained until learning was completed.

Study Period. The length of the study period for each of the three scores within the unit was kept as nearly constant as possible. Generally speaking the time required to play the score by the part-method, repeating each part three times, took approximately the same time as playing the corresponding score by the whole-method repeating it from beginning to end without a pause three times. The time taken to practise the part-method score usually set the time for the practice of the other two scores, but on no occasion did the practice terminate in the middle of a score; hence the daily records of practice time are not identical for each score although in the total practice time for an equal number of study periods the difference is negligible.

Time and Rotation. The scores were practised once every day between 10 and 12 A.M., except that on one or two occasions they were practised in the afternoon as well between 4 and 5. The order of practising was rotated, *i.e.*, each score was practised first in turn.

Time of Test. The test was taken immediately after the practice period except for a moment's pause to record the practice time.

Rotation of Difficulty. At first the method by which each score was to be learned was assigned by chance; but after the learning of the second unit an attempt was made to rotate the difficulty; *i.e.*, each method was assigned to the easiest, more difficult and most difficult scores in turn. This scheme was not carried out perfectly in the preliminary study, however, owing to the fact that two units had already been learned before the plan was adopted. A slight variation from the scheme will be noticed in unit 2.

Procedure. As has been said, a method was first assigned by chance to each score. In unit 1, minuet No. 6 was assigned whole-method; No. 7 part-method, and No. 8 combination-method. Three repetitions in practising the part-method were arbitrarily decided upon, as well as the size of the part (in this case, 4 measures).

a. Minuet No. 7 (part-method) was purposely chosen first because it was necessary to know the time required to repeat each part three times. With the metronome set at 40, a part consisting of four measures was played, at first with much confusion, and repeated three times. Then, without an appreciable pause, the next part was practised in the same way, and again the next until the twenty-four measures were completed. The time required was then noted and recorded. This was 5 minutes, 35 seconds.

With the metronome still ticking, the test was taken. Immediately afterwards the scores were recorded. Great difficulty was experienced in recalling the errors and defining them. It is by no means certain that all were recorded and that those errors were correctly defined. Accuracy increased, however, in this respect with decreasing errors.

b. After winding the metronome and noting the time, minuet No. 6 (whole-method) was played throughout three times. The time was recorded. The practice required 5 minutes, 30 seconds. The test was taken and errors recorded as for No. 7.

c. Minuet No. 8 (combination-method) was next played. The first mistake occurred in the third measure. This measure was repeated three times. Measures 4, 5 and 6 were successfully accomplished, but a mistake was made in joining measures 7 and 8. Those two measures were repeated three times. Measures 9 and 10 presented great difficulty. After three repetitions no accuracy ensued so the measure was repeated three times more. The rest of the minuet was then played without a mistake. With a glance at the watch a start was made again, all going well until measures 9 and 10 were reached where several mistakes occurred again and they were repeated twice three times as before. The departure from the intended number of repetitions was then recognized and never repeated. Another error occurred near the end at measure 23. This was interesting as it sounded very much like, and actually was identical with (although it was not then recognized), measures 7 and 8 where the second error had been made and corrected. At the end of the second practice the time 5 minutes, 30 seconds was noted.

Very early in practising by this method it was noted that in playing isolated measures or even two measures, the ticking of the metronome was disconcerting and very difficult to follow. This was experienced all through the study of unit 1, but it was specially noticeable at first.

TABLE I

DESCRIPTION OF SCORES USED

	Name of Score	Composer	Page	Number	No. of Measures	Key	Speed Objective ♩M =	Time
Unit I.....	Minuet (Carroll's Bach).....	Bach.....	6	6	24	G min	120	3/4
	" " "	"	6	7	"	G maj	"	"
	" " "	"	7	8	"	G min	"	"
Unit II.....	Minuet from French Suite.....	Bach.....	53		16	E maj	120	3/4
	" " Fugues and Preludes.....	"	11		"	G min	"	"
	" " French Suite.....	"	22		"	B min	"	"
Unit III.....	Germer's Selected Studies, Vol. I.....	Czerny.....	12	22	16	C maj	104	4/4
	" " " " ".....	"	30	43	"	D maj	"	"
	" " " " ".....	"	36	50	"	E min	"	"
Unit IV.....	Scenes from Childhood Op. 15.....	Schumann.....	5	3	12	B min	104	2/4
	" " "	"	10	8	1	F maj	"	"
	" " "	"	13	11	"	G maj	"	"
Unit V.....	Miniatures Op. 39.....	Reinhold.....	13	11	32	F maj	160	3/4
	" " "	"	8	6	"	F maj	"	"
	Album for the Young Op. 39.....	Tschaikowsky.....	30	23	"	G maj	"	"
Unit VI.....	Sonata No. 1.....	Mozart.....			22	C maj	112	4/4
	Bagatelle from Series for Young.....	Beethoven.....	5		"	B♭ maj	"	"
	Fifty Selected Studies.....	Heller.....	56	30	"	C maj	"	"

Second Investigation—Preliminary Investigation—

The test was taken immediately after the practice was accomplished. The performance was bad and great difficulty was experienced in collecting and labelling the errors. Again no claim to accuracy in the record is made.

d. On the next day the whole-method (No. 6) was practised first, the combination-method (No. 8) second and the part-method (No. 7) last. The same routine was followed except that the metronome was set at 44. Each day, while learning the first two units, the metronome rate was increased until 120 was reached where it remained fixed. Occasionally the scores were practised in the afternoon as well as in the morning and on these occasions the metronome rate was increased. A discrepancy, common to all the methods, was the fact that, after the third or fourth sitting, when a general idea of the music had been formed, a correction was often inadvertently made, without repetition, where the error was slight. For example, if F♯ were struck for F, the finger would quickly slip down to the required note.

On the completion of the first unit a second was immediately begun and the same routine followed throughout. A different type of music was chosen for the last unit. The three scores were studies in velocity. The whole-method was purposely assigned to the most difficult score, the combination to the easiest. The 'combination' score consisted mainly of long and sometimes broken scale passages not difficult to read at sight, as attested by the performance of the students.

The speed was not increased every day while learning this unit as was generally the case in learning the other two units. The metronome was moved down only when a certain degree of ease was experienced in playing at any one speed.

TABLE II

RESULTS OF PRELIMINARY TRIALS

Unit	Score	Method	Total Time of Perform'ce	Order of Diff'ty	Total Pract. Time Req. to Learn	Total No. Trials Req. to Learn	Order of Comple-tion	No. of Errors
	Minuet No. 6	Whole	9.3 min	2	27 min	7	1	10
1	Minuet No. 7	Part	8.53 "	1	39 "	13	2	62
	Minuet No. 8	Comb'ion	9.41 "	3	43 "	15	3	110
	Minuet p. 53	Whole	9.18 "	2	60.75 "	18	1	89
2	Minuet p. 22	Part	9.85 "	3	89.67 "	30	2	290
	Minuet p. 11	Comb'ion	9.02 "	1	98.54 "	34	3	261
	Czerny No. 50	Whole	15.8 "	3	136.72 "	45	2	315
3	Czerny No. 22	Part	14.09 "	2	111.29 "	35	1	261
	Czerny No. 43	Comb'ion	12.48 "	1	164.36 "	51	3	306

Interpretation of Results. It will be seen from Table II

that minuet No. 6, which was practised by the whole-method, was played perfectly for the first time on the seventh trial; No. 7 (part-method) on the thirteenth trial; and No. 8 (combination-method) on the fifteenth. It will also be seen that, judged by the students' performance, No. 7 was the easiest score, No. 6 more difficult and No. 8 the most difficult. The earlier perfection of No. 6 cannot therefore be explained by the relative easiness of the score. The explanation must be sought elsewhere, perhaps in the greater attractiveness of the music, perhaps in the method of learning. As for relative attractiveness the opinions of several competent music teachers were solicited but there was no agreement. There are very few objective criteria for attractiveness. Opinion, experience or mood may determine the decision. Hence the method of learning seems to offer a more cogent explanation of the earlier learning of No. 6.

Very early in the learning process it was noticed that fragments of the air of No. 6 came unsought to the subject and were purposely banished. It was some time later that bits of either No. 7 or No. 8 came unsought to mind. The reason may be that No. 6 was always heard as a whole, No. 7 in parts, although always the same parts, and that No. 8 was seldom heard twice in the same way. Here breaks for repetition occurred everywhere during the entire learning process although some breaks were more frequent than others. The results of units 2 and 3 bear out this suggestion so far as the combination-method is concerned. The isolating of any one of the measures of the long scale passages in the combination score of unit 3 played havoc with the continuity and hence with the learning.

The factor of velocity (M♩ = 104 with 16 notes in the measure), may offer a partial explanation of the relative inefficiency of the whole-method in unit 3. There was some indication that the part-method was not the most efficient in the early part of the learning, but that as speed increased the whole-method lagged behind. It seems more likely, however, that the reason for the lagging of the whole-method lies in the relative difficulty of the score itself.

Conclusions. In two of the units of this investigation the whole-method seemed more efficient than the part- or combination-methods. In the third unit the part-method seemed more efficient. In two of the units the results obtained by the part- and combination-methods were more nearly alike than the results of either one were to the results of the whole-method.

The Main Experiments

The preliminary investigation was faulty in at least five respects. (1) Practice time in learning unit 1 was inaccurately measured. (2) The distribution of practice was not a constant factor. (3) The rotation of difficulty of scores was inaccurate. (4) An accurate record of errors at the beginning of each learning, where a large number were made, could not be claimed. (5) The rate of increase of speed was not controlled. In learning units 1 and 2, speed was increased, as judged by gradations on the metronome, after every test. In learning unit 3 the speed was increased when a certain degree of ease was experienced in playing at any one speed, but there was no measure of the 'degree of ease.'

As little reliance could be placed on the conclusions of the preliminary investigation, a second investigation was undertaken with the purpose of reaching more reliable conclusions.

General Procedure. *a.* The scores for the units were chosen as before and they were rotated in difficulty after the first chance selection, *i.e.*, each method was used in learning, the easiest, the more difficult and the most difficult score in turn.

b. The methods of learning with their assigned scores were rotated in practice so that none would have the exclusive benefit of freshness of approach.

c. The practice time for units 4 and 5 was definitely fixed at 9 A.M. and 4 P.M In practising these units there was much bunching of practice, however, but with the rotation preserved near the completion of learning when practice time was short, owing to the increase in speed. The uniformity of the distribution of practice was accurately observed in unit 6. The hours selected for practice were 9 A.M., 1 P.M. and 4 P.M. and no bunching was permitted.

d. The test was taken at the end of every practice period as before.

e. Progress was measured mainly in terms of speed rather than in terms of error-elimination, which was, for the greater part, the method of measurement employed in the preliminary study.

f. The length of the part chosen in this investigation (for the part-method), was two measures. Four measures was the length used in the preliminary study.

g. The routine of practice was similar to that employed in the preliminary study with the important exception of the increase in speed. There the very elusive 'degree of ease' was the requirement, but in the experiments which follow the requirement was absolute perfection of performance.

Use and Limitation of Metronome. The slowest speed registered by the metronome was M♩ = 40, *i.e.*, 40 beats to the minute. If a score written in 4/4 time was played at the speed M♩ = 40, each measure required 4 × .025 min. = .1 min., and therefore a score containing 22 measures required 2.2 min. and for three repetitions 6.6 min. In actual practice the record of practice-time nearest this period for three repetitions of 22 measures of 4/4 time played at M♩ = 40 was 6.78 min. The period of .18 min. was consumed, possibly, between the repetitions.

In the learning of all the units except the last one (unit 6) the initial speed was M♩ = 40. In learning unit 6, by counting 8 beats to the measure and playing at M♩ = 40, a speed record of M♩ = 20 was obtained, *i.e.*, every measure required .2 min. and the whole score of 22 measures required 13.2 min., the nearest approach to which in actual practice was 13.5 min.

TABLE III

RESULTS OF THE MAIN INVESTIGATION

Unit	Score		Method	Total Time of Perform'ce (min)	Order of Diff'ty	Total Pract. Time Req. to Learn (min)	Total No. Trials Req. to Learn	Order of Completion
	Schumann	8	Whole	8.8	1	106.81	40	1
IV	"	3	Part	10.64	3	197.49	96	3
	"	11	Comb'ion	9.55	2	175.7	43	2
	Tschaikowsky	23	Whole	14.76	2	161.32	29	1
V	Reinhold	6	Part	13.98	1	257.75	65	3
	"	11	Comb'ion	15.21	3	227.76	53	2
	Heller	30	Whole	29.54	3	285.05	49	2
VI	Beethoven		Part	23.19	2	280.55	52	3
	Mozart		Comb'ion	22.63	1	271.03	46	1

Because of the particular gradations on the metronome the amount of increase in speed could not be uniformly maintained throughout the whole learning. As measured by

gradations on the metronome, speed was increased by 4 degrees from a rate of ♩ = 40 to ♩ = 60; by 6 degrees from ♩ = 60 to ♩ = 72; by 8 degrees from ♩ = 72 to ♩ = 120, and by gradations of 12 from ♩ = 120 to ♩ = 144, and 16 from ♩ = 144 to ♩ = 160.

TABLE IV

NUMBER OF TRIALS REQUIRED BY EACH METHOD IN EACH UNIT TO ACHIEVE PERFECTION AT VARIOUS SPEEDS

Gradations in Speed	Unit IV			Unit V			Unit VI		
	Whole	Part	Comb.	Whole	Part	Comb.	Whole	Part	Comb.
M. ♩ = 20..							5	7	5
Incr'ed to 40..	17	26	20	5	8	12	11	16	7
44..	18	33	22	6	13	13	12	17	10
48..	20	38	23	7	16	14	16	20	15
52..	21	42	25	8	19	15	17	21	17
56..	23	45	28	9	24	18	21	24	21
60..	26	52	29	10	25	19	23	26	24
66..	27	55	30	11	30	20	24	28	26
72..	30	57	31	12	32	21	26	29	27
80..	31	62	32	13	33	22	29	31	28
88..	32	74	36	15	34	23	31	36	29
96..	34	84	39	16	35	24	34	39	31
104..	40	96	43	19	41	28	42	45	35
112..				20	43	31	49	52	46
120..				21	44	32			
132..				23	58	44			
144..				26	60	45			
160..				29	65	53			

INTERPRETATION OF RESULTS

By referring to Table III (for unit IV) it will be seen that the order of difficulty of the scores coincided with the order in which they were completely learned, a fact which seems, on the surface, to need no explanation. But when the difference between the whole and the combination learning and the difference between the combination and part learning are compared, in respect to the total time of students' performance, with similar differences in total number of trials (*i.e.*, 9.55 min − 8.8 min = .75 min :: 43 trials − 40 trials = 3 trials; 10.64 min − 9.55 min = 1.09 min :: 96 trials − 43 trials = 53 trials) it will be evident that some explanation is necessary. Why was learning so long retarded in the 'part' score? The answer seems to lie in the type of the score itself and also in the method of learning.

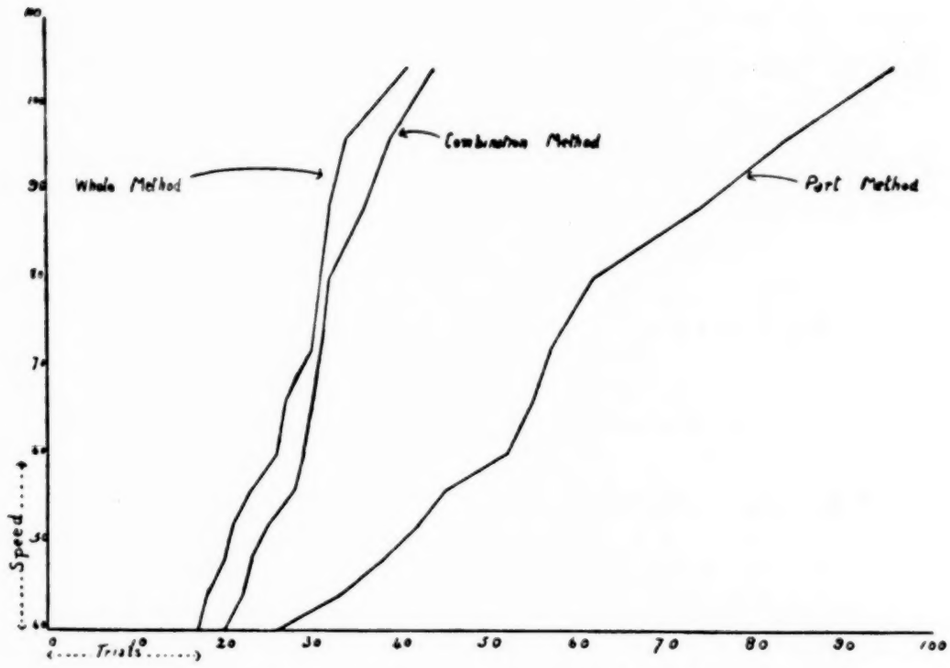

FIG. 1. Progress in learning Unit IV.

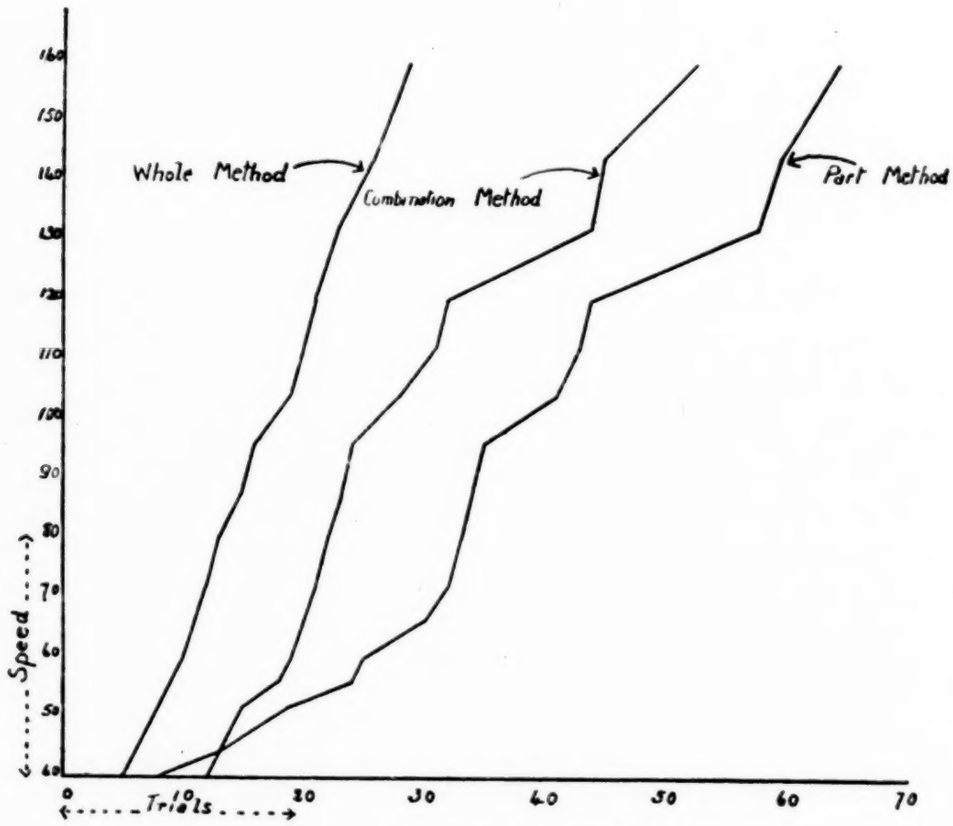

FIG. 2. Progress in learning Unit V.

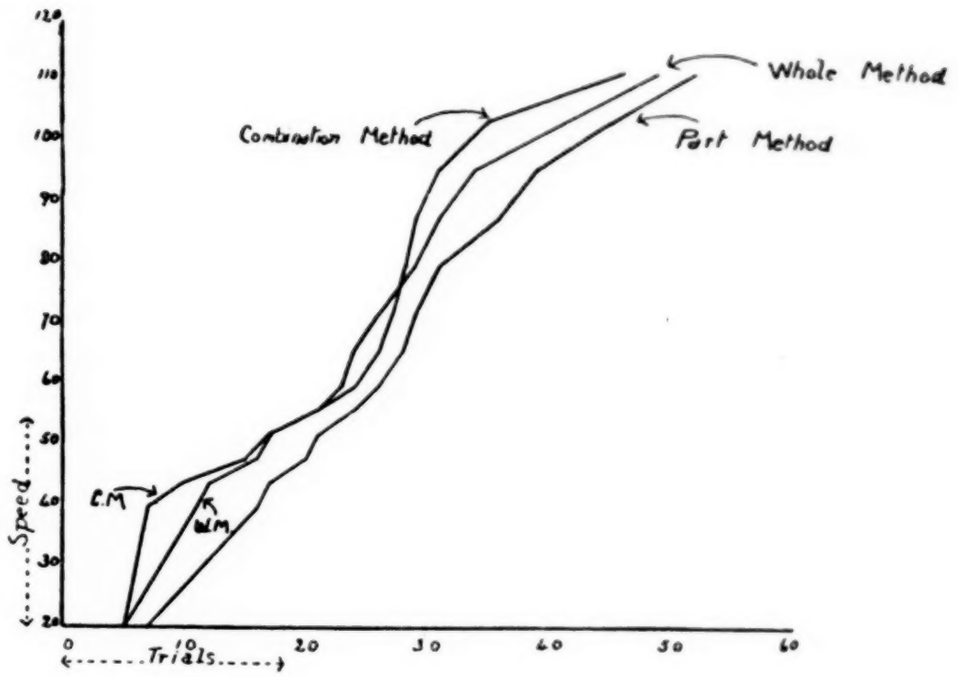

FIG. 3. Progress in learning Unit VI.

The 'part' score of unit 4, besides being more difficult to read, was one which was closely knit and one in which there was great cohesion, and, by practising it in bits, great violence was done to the meaning or satisfyingness of the music as well as to the fingering sequences.

Again, such habits of returning to the beginning of the part were formed that some difficulty was found in breaking them. On one or two occasions, during a test at high speed, playing was continued half-way through a part, making for a second repetition, before it was noticed that a return had been made. This tendency to return was also noticed in taking the test on the 'part' score in unit 5; but it was not so marked, and in taking the test on the 'part' score of unit 6 this tendency was not noticed at all, neither did the method seem to break up meaning to any extent in this score.

Another factor which seemed to be one of the causes of the relative inefficiency of the part-method was that the connecting of the end of one part with the beginning of the next received less practice than any other connection. In the 'part' score of unit 5 there were four cases where special

difficulty existed at the bridge between two parts. This difficulty was in the repeating of the last note of one unit as the first note of the next unit with a different finger. This insufficiency of practice of difficult connections was noticed in learning the part-score of unit 6; but it was not so marked as in unit 5.

The relative efficiency of the whole-method may be explained by three factors; first, the test was made on the identical act which was practised; namely, playing the score from beginning to end without a break. Secondly, attention was not distracted from the whole by having to fixate on errors as was the case in the combination-method. Thirdly, meaning or satisfyingness was never violated by forced pauses. Attractiveness, a factor which was difficult to control, was more likely to be noticed in practising by the whole-method than by either of the other two.

Referring to Table III again it will be seen that in unit 6 the 'whole' score was the second to be completely learned. The score itself was more difficult than the other scores in the unit and, besides, it had a peculiarity which seemed to retard learning. The little finger of the right hand was required to play an accented note 32 times in the 22 measures. After playing the score three times, the little finger had accented 96 times so that by the time the test was taken it was often weak and uncertain. This was particularly noticeable at high speed.

By reducing errors to a minimum at the outset, the combination-method became very much like the whole-method. Over and over again it was noticed that the score was practised throughout without a mistake. In the preliminary study the combination-method was more like a part-method.

It will be noticed (Table III) that the part-learning of unit 6 required 4.5 min. less time than the whole-learning; although the part-learning required three more trials than the whole-learning. The only explanation that can be offered is that at the beginning of the learning, when a very slow speed (M♩ = 20) was used, it was difficult to be accurate.

For the first five trials 61.64 min were spent on the part-method and 68.48 min on the whole;—a deficiency of 6.84 min in 'part' practising time. This seems to explain the deficiency in the total 'part' practising time.

Summary

Of the three methods studied, the whole-method of learning piano music was the most efficient in two units out of three. In one case the whole-method was assigned the easiest score and in the other it was assigned the score of medium difficulty. When the most difficult score was assigned to the whole method it ranked second of the three methods in efficiency.

The part-method was the least efficient of all. The degree of inefficiency of this method seemed to be a function of the type of score.

The combination method was most efficient on the single occasion when the easiest score was assigned to it. It ranked second in efficiency when the score of medium difficulty was assigned to it and again second when it was used on the most difficult score.

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A NEW TYPE OF ELECTRODE FOR THE GALVANIC SKIN REFLEX

BY ALVHH R. LAUER

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Next to a high-grade galvanometer one of the most important items in the apparatus used in studies of the galvanic reflex is the electrode. One must know exactly what kind and how much of a contact is being made during an experiment in order to interpret the results. Whatever may be the effect of the polarization, the constancy of the contact is essential in allowing for this frequent source of error. Whether bodily resistance is due to muscular action, blood changes, glandular secretions, secretory changes of the skin or what not, so long as results are consistent the galvanic reflex will remain an important measure of emotional reactions.

Various means of establishing and maintaining a contact have been utilized; but often the chance for error has been large. Especially is this true in methods employing the Tarchanoff method of measuring direct electromotive force alleged to be caused by emotional states. In many cases, in spite of the attempt to use non-polarizable electrodes, the 'electromotive force,' as it is called, generated by the body is likely to be a function of the electrolytic effect of the solution used for making a contact, combined with a variation in constancy of the contact.

The author found through an extended search for a suitable electrode that large deflections in the galvanometer could be induced by varying the pressure on the electrode, its position on the body and the kind of electrode used. Various materials (copper, zinc, gold, platinum, silver, tin, iron, nickel, mercury, zinc oxide, collodium and kaolin) were used; but with the uniform result of electrolytic effects as soon as a conducting medium was introduced which would insure the proper transmission of current. In measuring resistance of the body the uniformity of contact is of the highest importance, as resistance is a function of the electrode and its connection with a bodily region.

Numerous attempts to offset this difficulty have been employed by various experimenters. Tarchanoff used non-polarizable electrodes made of clay, Sidis and Nelson used platinum hypodermic needles, Radecki zinc, and Einthoven zinc sulphate electrodes. Zinc electrodes covered with chamois skin have been used by Waller, Smith, and Wechsler. Féré used nickel-plated brass cylinders attached to the palm of the hand, Peterson and Jung copper plates, while McCarthy and Radecki employed brass plates. Sidis and Kalmus used liquid electrodes in which the hands and feet were immersed and Fleming has used liquid electrodes in which the fingers are dipped. Syz

used kaolin and zinc oxide for a contact. Darrow has devised a special type of electrode consisting of a zinc plate with a bakelite back attached to a moisture-sensitive device which measured moisture changes on the skin by introducing a second galvanometer. Others have used various mercuric, zinc and sodium solutions with varying degrees of success.

The inadequacy of the types of electrodes mentioned above may come under one of the following headings, with the possible exception of the platinum hypodermic type which would be decidedly inconvenient to attach and to retain without exciting the subject.

1. There is slight chance of maintaining a uniform contact with any metallic electrode either with or without a chamois skin covering due to the rapid evaporation of the contact agent and the difficulty of keeping the contact surface constant.

2. Any electrode requiring greatly increased pressure on the body introduces an additional variable.

3. With the alleged 'non-polarizable' electrodes there is some question as to the verity of the claims. The effect may be apparently eliminated but the fact remains that usually somewhere in the circuit there is a connection that will introduce polarization.

4. Electrolytic effects are likely to appear and when measuring electromotive force the contact, pressure and surface must be kept constant to assure consistent results.

After considerable trouble with conventional electrodes the author hit upon the following device which has given more satisfactory results than any other type so far used in his experiments.

The electrode consists primarily of a Gooch funnel (4, on Fig. 1) cut about three centimeters below the reduction. It is surrounded (at 3) by an insulating material, preferably soft rubber. At 2 the small part of the funnel was cut and a chromium or platinum wire fused into the glass. The electrode proper (at 5) may be either simply a wire turned in a semi-circular shape or a straight wire with a small plate of the same material resting about 0.5 cm above the level of the funnel mouth. Across the top of the electrode is fastened a small strap (at 1) with an insert of elastic and a slip-buckle. Within the receptacle or funnel any liquid or paste contact-medium, such as mercury, sodium or zinc solutions, may be used. While it is most conveniently fastened to the palm of the hand, there is no reason why such a device of convenient proportions could not be strapped to other parts of the body.

It is more convenient to attach the electrode from the

inverted position (open end up) and to have the subject turn over his hand when the adjustment has been carefully made. By having a suitable rest for the hands, little trouble

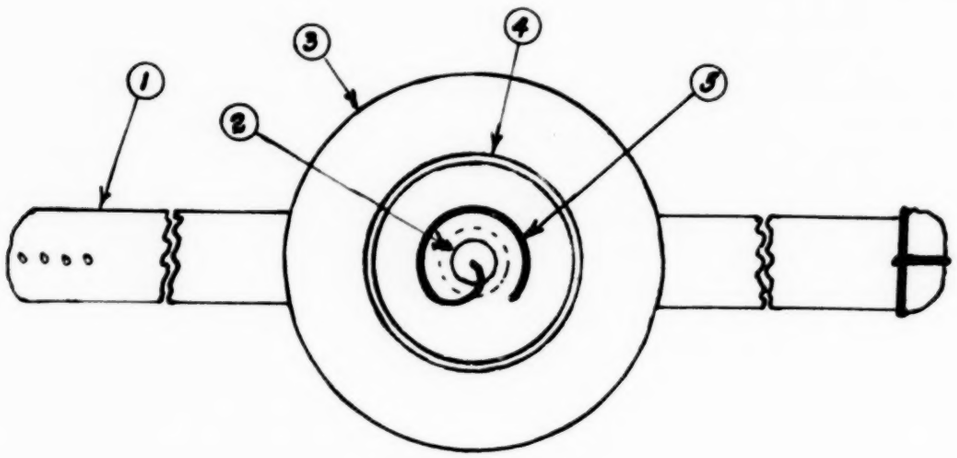

FIG. 1. End view

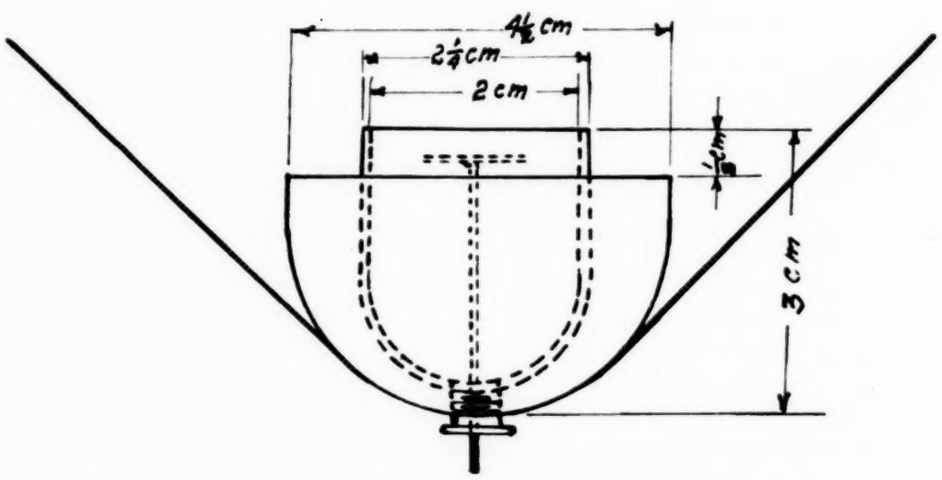

FIG. 2. Side view

is experienced in keeping the solution in the receptacle. In case the subject should move, the loss of any significant quantity of liquid or metal can be detected so as to safeguard the results obtained.

This electrode has the advantages of the nearly perfect contact which Sidis and Kalmus can claim for their liquid electrodes with the added advantage of a uniform amount of contact surface. A relatively constant as well as a minimal

pressure on the body-surface reduces the chance of error in measurement.

The author has found the above device to be much superior to various other types of electrodes and recommends it as worthy of trial by any investigator of bodily resistance or change in electrical potential due to emotional or other states.

(Manuscript received Nov. 4, 1927)

PERIODIC FLUCTUATIONS IN THE EXTENT OF THE KNEE JERK AND THE ACHILLES JERK

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AND

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In studying records of the knee-jerk and of the Achilles-jerk obtained in various experiments by the present writers and by other workers, apparent periodic fluctuations in the extent of the two jerks were noted. There were available at the time records of both jerks on over a hundred normal subjects comprising about equal numbers of men and women. Records of thirty of these subjects who furnished good jerks were selected for further study. The knee-jerk had been elicited at a rate of 7 per minute and the Achilles-jerk at 10 per minute.[1] An analysis of these records, which meant a careful measurement of the height of the jerks and subsequent graphing of the readings, revealed periodic fluctuations in the extent of the knee-jerk at an average frequency of 2.03 per minute and for the Achilles-jerk at an average frequency of 3.03 per minute. These averages of individual frequencies are shown in Table I.

In attempting to account for the difference in frequency of the periodic fluctuations for the two jerks, the difference in rate of stimulation immediately came to mind. Is the frequency of the fluctuation in extent of the jerks dependent upon the rate of stimulation?

Five of the thirty subjects were selected for still further study. Two additional rates of stimulation, one slower and one faster for eliciting the Achilles-jerk and one faster rate for eliciting the knee jerk, were used. Table II, when taken in connection with Table I, shows that there is a progressive increase in the frequency of the periodic fluctuations in extent of the two jerks to correspond with the progressive increase in rate of eliciting them and that the two jerks give practically the same fluctuation frequency when elicited at the same rate. This is seen again in Table III, which shows also, according to the standard deviation and the range, that the fluctuation frequency for individuals varies only slightly from the average of the group.

That increases in rate of elicitation produce significant increases in the frequency of the periodic fluctuations in extent is seen by a statistical consideration of the data.

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[1] The apparatus and technique have been described elsewhere (Tuttle and Travis, *Amer. J. Physiol.*, 1927, 32, 147). The apparatus automatically delivers blows of uniform intensity, at a constant rate, to the tendon. For the Achilles-jerk it can be adjusted to furnish blows at the rates of 7, 10, and 15 per minute and for the knee-jerk at the rates of 7 and 10 per minute. All of the subjects were students of the University. Controlled conditions of silence, quiet and rest were maintained for each subject for both jerks.

TABLE I

INDIVIDUAL RECORDS FOR THIRTY SUBJECTS

Subject	No. periodic fluctuations in extent per min of the K. J. elicited at rate of 7 per min	No. periodic fluctuations in extent per min of the A. J. elicited at rate of 10 per min
1	2.1	3.2
2	2.1	2.7
3	2.0	3.1
4	1.9	3.0
5	2.3	2.9
6	1.7	2.6
7	2.1	2.9
8	2.3	3.4
9	2.0	3.0
10	1.9	3.0
11	2.0	3.4
12	2.0	3.0
13	2.1	3.2
14	2.2	2.8
15	2.1	3.1
16	1.8	3.3
17	2.0	3.1
18	2.0	3.1
19	2.0	3.0
20	2.0	3.0
21	2.4	3.0
22	2.1	3.0
23	2.2	3.0
24	1.7	3.0
25	1.8	3.0
26	2.2	2.7
27	2.2	3.1
28	1.9	3.0
29	1.9	3.3
30	1.9	3.0
Mean	2.03	3.03

Let a jerk, the Achilles-jerk for instance, elicited at a certain rate, be represented by the usual abbreviation carrying the rate of elicitation as a sub-figure and let an 'equals' sign following this symbol signify the production of the stated fluctuation frequency by the given elicitation frequency.

Then we have

$$\text{K. J.}_{7} = 2.03$$
$$\text{K. J.}_{10} = 3.05$$
$$\text{A. J.}_{7} = 2.20$$
$$\text{A. J.}_{10} = 3.03$$
$$\text{A. J.}_{15} = 5.04$$

TABLE II

INDIVIDUAL RECORDS FOR FIVE SUBJECTS

Subject	Knee-Jerk: No. periodic fluctuations in extent per min when elicited at rate of 10 per min	Achilles-Jerk: No. periodic fluctuations in extent per min when elicited at rate of 7 per min	Achilles-Jerk: No. periodic fluctuations in extent per min when elicited at rate of 15 per min
A	3.1	2.1	5.1
B	2.9	2.3	4.8
C	2.8	2.2	5.2
D	3.3	2.3	5.0
E	3.1	2.1	5.1
Mean	3.05	2.2	5.04

TABLE III

SUMMARY OF TABLES I AND II

	Knee-Jerk		Achilles-Jerk		
	Elicited 7 per minute	Elicited 10 per minute	Elicited 7 per minute	Elicited 10 per minute	Elicited 15 per minute
Mean	2.03	3.05	2.20	3.03	5.04
S. D.	.13	.11	.09	.12	.13
Range	2.4−1.7=.7	3.3−2.8=.5	2.3−2.1=.2	3.4−2.6=.8	5.2−4.8=.4
No. of Subj.	30	5	5	30	5

Three essential equations follow:

$$\text{A. J.}_{10} - \text{A. J.}_{7} = 3.03 - 2.20 = .83 \pm .03 \text{ [2]}$$
$$\text{A. J.}_{15} - \text{A. J.}_{10} = 5.04 - 3.03 = 2.01 \pm .04$$
$$\text{K. J.}_{10} - \text{K. J.}_{7} = 3.05 - 2.03 = 1.02 \pm .03$$

All of these differences are significant.[3]

The statement that when the two jerks are elicited at the same rate they present the same frequency in the periodic fluctuations of extent is statistically true, for an elicitation rate of 10 per minute, as seen by

$$\text{K. J.}_{10} - \text{A. J.}_{10} = 3.05 - 3.03 = .02 \pm .03;$$

but it is not entirely correct for an elicitation rate of 7 per minute, as seen by

$$\text{A. J.}_{7} - \text{K. J.}_{7} = 2.2 - 2.03 = .17 \pm .03$$

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[2] The amounts following the plus-minus signs are probable errors of the observed differences. They were obtained by the formula, $\text{P.E.}_{\text{diff}} = \sqrt{\text{P.E.}_1^2 + \text{P.E.}_2^2}$ where P.E._1 = probable error of the first mean and P.E._2 = probable error of the second mean.

[3] An observed difference is considered statistically significant if it is at least three times its probable error.

In this latter instance, although the observed difference is sufficiently larger than its probable error to make it significant, it is markedly smaller than the three differences noted above.

Table IV and Figures 5 and 6 show the close correspondence between an increase in the rate of elicitation and an increase in the frequency of the periodic fluctuations in extent. In both jerks there appears to be a tendency, however, for the fluctuation frequency to increase slightly faster than the rate of elicitation.

TABLE IV

INCREASE IN RATE OF ELICITATION *vs.* INCREASE IN FREQUENCY OF PERIODIC FLUCTUATIONS

	Knee-Jerk		Achilles-Jerk		
Rates of Stimulation	7	10	7	10	15
Frequency of Periodic Fluctuation	2.03	3.05	2.2	3.03	5.04
Per cent. of Increase in Rate of Stimulation		40		40	50
Per cent. of Increase in Frequency of Fluctuation		50		40	70

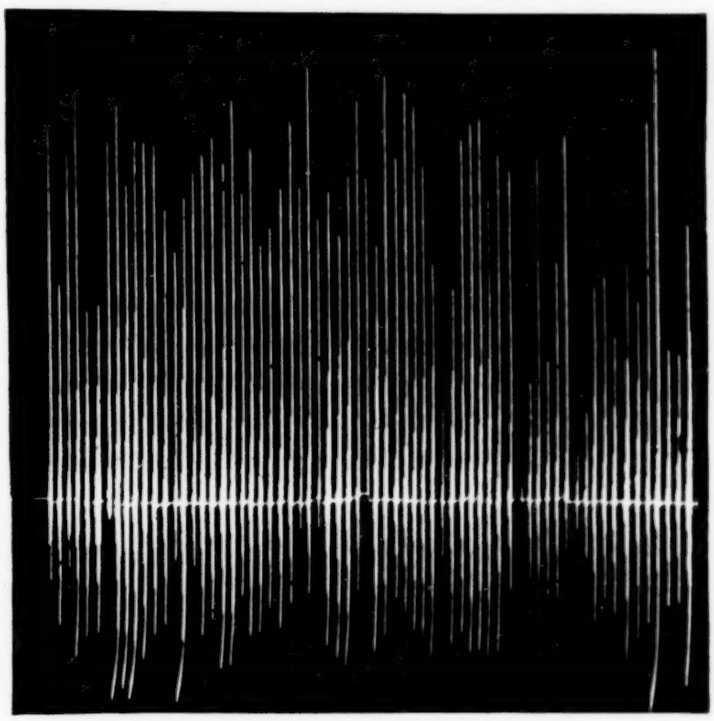

FIG. 1. Typical record of the knee-jerk elicited 7 times per minute

There is another way of looking at the statement that the frequency of fluctuation is a function of the rate of stimulation. This is brought out in Table V, where it is noted that, regardless of the rate of eliciting either jerk, each periodic fluctuation in extent contains on the average a fraction more than three jerks. In other words, the two reflex movements studied increase and decrease in extent about every third movement independently of the rate of elicitation.

This study revealed no differences between men and women.

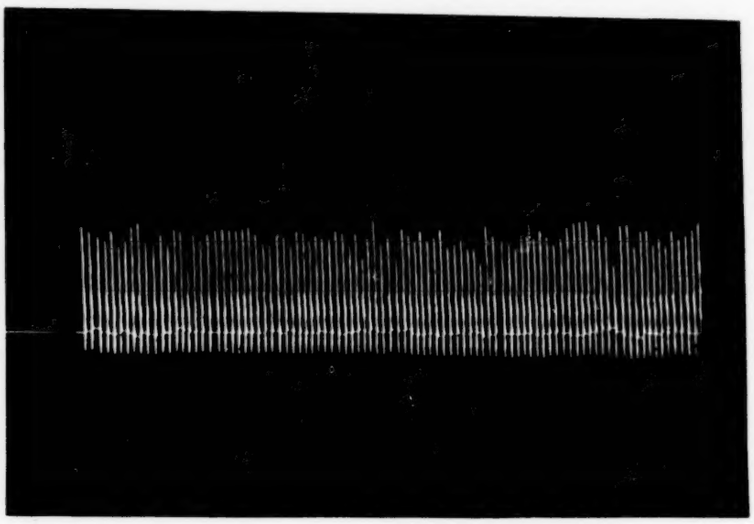

FIG. 2. Typical record of the Achilles-jerk elicited 10 times per minute

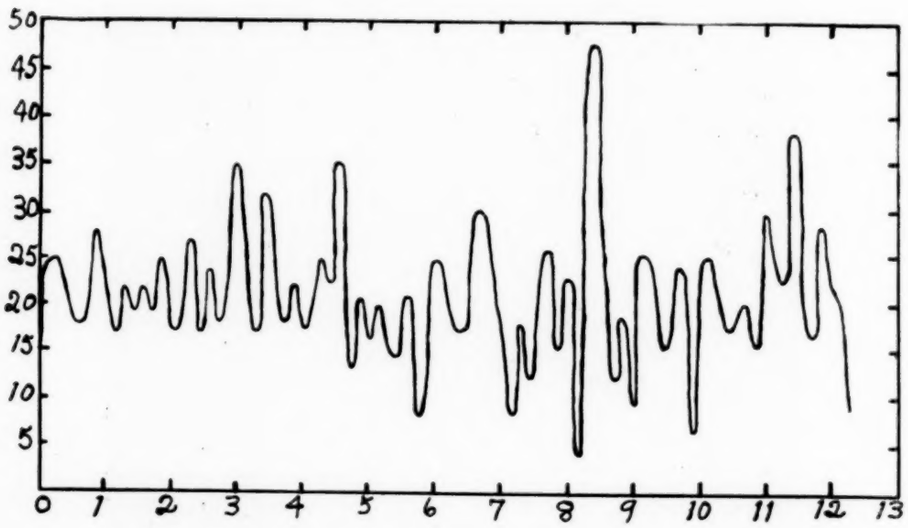

FIG. 3. Graph of the periodic fluctuations in the extent of the knee-jerk elicited 7 times per minute. In Figures 3 and 4 the ordinate scale gives the height of the jerks in mm and the abscissa consecutive minutes.

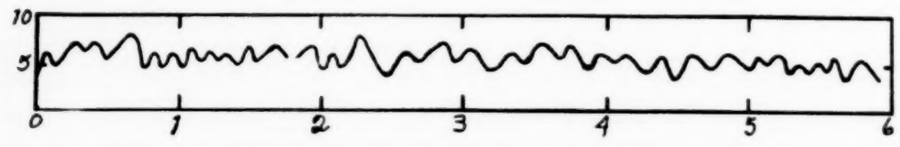

FIG. 4. Graph of the periodic fluctuations in the extent of the Achilles-jerk elicited 15 times per minute.

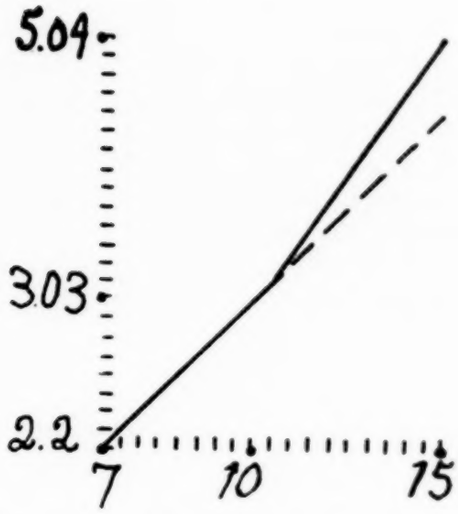

FIG. 5. The solid line shows the relationship between increase in rate of eliciting the Achilles-jerk and increase in the frequency of the periodic fluctuations in extent of the jerk. It is seen that there is a tendency for a certain per cent. of increase in the former to produce a slightly greater per cent. of increase in the latter. The broken line shows a perfect theoretical correspondence between increase in rate of eliciting the Achilles-jerk and increase in frequency of its periodic fluctuations. The ordinate scale gives the fluctuation-frequency and the abscissa the rate of elicitation; both in minutes. The small divisions on both scales represent 5 per cent. Thus 10 is 8 divisions or 40 per cent. more than 7.

FIG. 6. Same as Fig. 5. except that it is for the knee-jerk

TABLE V

AVERAGE NUMBER OF JERKS PER FLUCTUATION AT THE VARIOUS RATES OF ELICITATION

Rate of Elicitation	Knee-Jerk	Achilles-Jerk
7	3.4	3.2
10	3.3	3.3
15		3.0

SUMMARY

1. Periodic fluctuations in the extent of the knee-jerk and the Achilles-jerk were found to exist in normal subjects under controlled conditions of quietness and restfulness.

2. Different rates of elicitation of the jerks produced different frequencies of fluctuation in extent of the jerks.

3. There appears to be a tendency for a certain per cent. of increase in rate of elicitation to produce a slightly greater per cent. of increase in the frequency of fluctuations in extent.

4. Regardless of the rate of eliciting either jerk, each periodic fluctuation in extent contains on the average a fraction over three jerks.

5. No differences were found between men and women.

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